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NEUROPHYSIOLOGICAL SYMPOSIUM*

RECENT ADVANCES IN NEUROPHYSIOLOGY*

JOHN F. FULTON, M.D.

Department of the History of Medicine, Yale University School of Medicine, New Haven, Connecticut

(Received for publication October 1, 1953)

SEVERAL years ago, at a meeting of the American Neurological Association, Stanley Cobb[7] did us the honor of referring in his presidential address to our work on the frontal lobes, and having his discussion well planned, he produced from his pocket a lantern slide which was thrown on the screen. I recognized it immediately as Becky, our first frontal lobe chimpanzee, and with apologies to Marlowe and *Dr. Faustus*, Cobb asked

"Was this the face that lopped ten thousand lobes,
And burnt the topless towers of Ilium?"

The gathering was rather taken aback, but even in a gallant audience of neurosurgeons, no one rushed forth to exclaim

"Sweet Becky, make me immortal with a kiss."

However, our colleagues in this Society and elsewhere in the neurosurgical world have been courting Becky ever since and, I am sure, have now lopped another ten thousand lobes without being fully aware of some of the cosmic issues involved. I say this with no desire to be critical, but in the hope that those who are dealing surgically with mental disease will continue to study their patients with the same thoroughness with which chimpanzees are studied, for you have a much finer opportunity to gain insight into some of the basic problems of frontal lobe function than we who are limited to gaining information from inarticulate beasts.

In arranging this program, Dr. MacLean and I have attempted to stress recent neurological advances of the past five years; my remarks will be based in part on a review on the somatic nervous system which appeared in *Annual Review of Physiology*[12] of 1953.

At the San Francisco meeting of the Harvey Cushing Society five years ago I read a paper entitled "The frontal cortex and visceral pain" in which it was suggested that the reason why intractable pain was relieved by frontal lobotomy stemmed from the fact that the standard lobotomy interrupted a large system of ascending afferents from blood vessels and the hollow viscera. A number of friendly members of the Society assured me that I was generalizing beyond available data (which was of course true) and the com-

* Presented at the annual meeting of the Harvey Cushing Society, Hollywood, Florida, April 23, 1953.

munication has remained unpublished. The paper carried the following summary:

"The concept which I have placed before you recognizes somatic pain as pertaining to the spinothalamic system, and it suggests that the autonomic afferents—responsible for visceral pain as well as the other sensory modalities in the visceral sphere—pass up the spinal cord, probably in discrete pathways, and give rise to a true spinohypothalamic system which passes through the medulla and pons alongside the medial lemniscus as the mammillary peduncle. It also recognizes the frontoorbital cortex as the principal autonomic center of the forebrain."

Perhaps the most important development in neurophysiology of the past five years has been the clear-cut separation of the limbic system, or "visceral brain" as MacLean[20] has designated it, from the neocortex which is concerned with higher intellectual functions. The *limbic system*, according to Broca's original definition, lies within the boundaries of the limbic fissure and includes such midline structures as the pyriform area, the hippocampal gyrus, the hippocampus itself, the parasplenial, cingulate, and subcallosal gyri. While by definition the insula, temporal pole, and the medial and posterior orbital gyri are strictly speaking outside the limbic lobe, these areas are histologically and functionally akin to the pyriform. The limbic system projects to various subcortical areas such as the amygdala, anterior thalamic nuclei, the hypothalamus, the basal ganglia and various pontine structures. Dr. MacLean deals more at length with the reactions that follow upon stimulation and ablation of various elements in the limbic complex.[21]

LIMBIC AFFERENTS

It is customary to believe that the chief ascending systems in the forebrain pass by the medial lemniscus to the ventral nuclei of the thalamus and thence in precise topographical fashion to the pre- and postcentral convolutions of the cerebrum. Little attention has been given in the past to other possible afferent channels passing to the hypothalamus and related structures. Bronk and his associates[6] showed that stimulation of certain medullary nuclei activates various elements of the hypothalamic complex. Amassian[1,25] and others found on stimulation of the central end of the splanchnic that the sensory trunk area of the postcentral convolution was activated but that other and slower fibers in the splanchnic activated the hypothalamic area, and that the fibers in question did not pass to the thalamus as such. A detailed study of the afferent paths from the vagus in the forebrain has recently been made by Dell,[9] who finds specific and nonspecific autonomic projections passing to the forebrain in the cat, the specific projections (homologue of the classical projections of the somatic system) passing to the posterior orbital gyrus (latency 8 to 10 msec.), thus confirming Bailey and Bremer—this after relay in the most medial part of the nucleus ventralis posterolateralis (latency 5 to 6 msec.). The nonspecific autonomic projections, passing to regions which they have in common with the nonspecific somatic projections, have been traced to many parts of the brain stem, the

thalamus and the basal ganglion. One group of projections (latency 8 to 10 msec.) passes to the lobulus simplex of the cerebellum.

In the work of Dell and Amassian and the more recent studies of MacLean and Delgado[22] we thus have convincing evidence in support of the hypothesis that the relief of pain following lobotomy may result from interruption of afferent fibers passing to the limbic complex. It is evident, furthermore, that many of these fibers are well localized, passing for the most part in the medial ventral quadrant of the frontal lobe to the insula and orbital gyri. In behavioral studies presented at the 1953 Federation meetings in Chicago Delgado and Rosvold[8] reported that monkeys trained in visual discrimination and also in an alternation test suffered no deficit when medial structures in the superior part of the frontal lobe were destroyed, but that when lesions were made in a sharply localized focus of the medial ventral quadrant the monkeys failed in the alternation test while the visual discrimination habit continued unimpaired. Following bilateral lesions of the medial ventral quadrant, the animals also showed behavioral changes, but they did not exhibit the "intellectual" deficits seen in animals that have been subjected to a bilateral radical lobotomy. These observations are in keeping with those of Grantham,[15,16] who finds in man that medially placed lesions tend to be as effective in relieving pain and also certain psychoses as the more radical standard lobotomy and are followed by less intellectual deterioration. Since such restricted lesions do not involve projections to the neocortex they will come, I believe, to replace the radical standard lobotomy.

But the theoretical implications of these ascending autonomic afferents are far greater than this immediate practical application in relieving pain. As MacLean points out,[21] they must provide the anatomical basis of the aura and various viscerally projected sensations that accompany the psychomotor epilepsies.

PYRAMIDAL AFFERENTS

Another surprising disclosure made within the past year by Brodal, Kaada and others in Oslo lies in the clear-cut proof that at least 4 per cent of the fibers in the pyramidal tract are afferent rather than motor. Brodal and Walberg,[5] using the Glees silver impregnation technique, believed that they had demonstrated the existence of *ascending* fibers in the cat's pyramid, originating for the most part in the upper extremities and projecting directly to the sensory cortex via the internal capsule, bypassing the thalamus. This paper evoked considerable comment, some of it highly skeptical. Brodal and Kaada, however, now find electrical evidence of ascending elements in the pyramid, the details of which are described in the *Journal of Neurophysiology*:[4]

"The electrical activity set up in the pyramidal tract fibers by an afferent volley from various cutaneous and muscular nerves consists of several positive deflections followed by a low-voltage negative wave. The responses to stimulation of cutaneous

nerves are considerably larger than those evoked from muscular nerves and show more distinct deflections, suggesting the presence of groups of fibers of different conduction velocities. There are striking similarities between the ascending and descending pyramidal fiber systems. Thus, the majority of ascending fibers, like the descending ones, appears to be crossed; further, the pyramidal response is greater when stimulating nerves of the forelimbs than of the hindlimbs and greater when induced from nerves supplying the distal parts of the limbs than from nerves innervating the proximal parts; the termination of the ascending fibers in the cerebral cortex finally is much the same as the origin of the descending pyramidal fibers. The suggestion is ventured that they are in some way of importance for the coordination of differentiated, skilled movements, and further that they may represent the still unknown afferent path in the plantar and abdominal reflexes and in the placing and hopping reactions."

With the neocortex and limbic systems properly separated at the cortical level, it is now possible to proceed more conventionally from the spinal level rostrally.

OTHER LEVELS OF FUNCTION

Spinal Cord. Since the end of World War II there has been a vast change of attitude toward cases of spinal transection, this being attributable largely to the application of sound physiological principles in the management of such paraplegics. Through careful nursing, avoidance of infection and of the overdistended bladder, reflexes begin to return sometimes after only a few days, and after a month or two the extensor reflexes, as Freeman,[10,11] Kuhn and Macht,[18] and others have shown, begin to be almost as brisk as the flexor reactions. Such patients may become ambulatory, and with hand-controls some have learned to drive cars and airplanes, and there are a number of instances of men with complete spinal transection who have married and had children.

Physiological studies on animals indicate that the character of a given spinal reflex evoked from the skin surface depends upon the area of skin stimulated. Thus Hagbarth[17] finds that the extensor muscles are excited from most skin areas of the limb but are inhibited from the skin lying over the muscle itself. This observation undoubtedly has clinical implications which as far as I am aware have not yet been studied.

In a series of notable papers on the stretch reflex, Granit and his pupils[13,14] in Sweden have established the muscle spindle as unmistakably the stretch afferent but they find that the degree of its responsiveness in any particular instance is governed by motor innervation by gamma fibers from the spinal cord. The responsiveness of the spindles is thus determined by influence of central origin.

Reticular Formation. One of the most significant disclosures in the recent history of neurophysiology is the important role played by the reticular formation in coordination of posture and locomotion through interplay of its vast facilitatory and inhibitory areas both on spinal neurons and on those of the cerebral cortex. Magoun and his associates[23,24,26] have been largely responsible for elucidating the function of this important region of the brain stem. The nature of the interaction occurring between the reticular forma-

ion and other parts of the central nervous system is shown in Magoun's diagram (Fig. 1) which indicates that the neocortex and probably also the limbic system play upon the reticular centers as does the cerebellum. The clinical implications of Magoun's work are not yet fully appreciated but it is

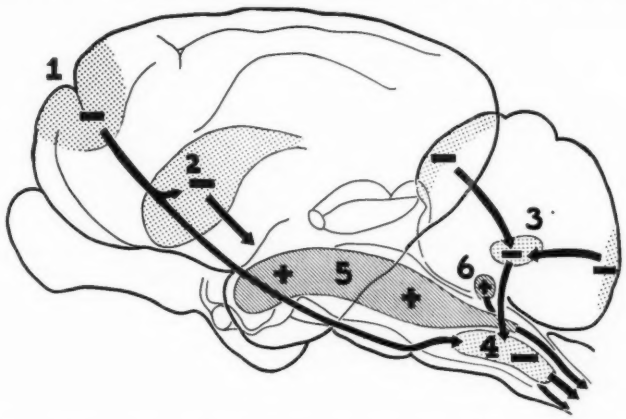

FIG. 1. Reconstruction of the cat's brain showing the suppressor and facilitatory systems concerned in spasticity. Suppressor pathways are 1: cortico-bulbo-reticular, 2: caudato-spinal, 3: cerebello-reticular, 4: reticulo-spinal. Facilitatory pathways are 5: reticulo-spinal, 6: vestibulo-spinal. (Reproduced from Lindsley, Schreiner, and Magoun.[19])

clear that the poliomyelitis virus as well as that of encephalitis has a remarkable affinity for the reticular formation which no doubt accounts for many of the bizarre symptoms encountered in the early stages of these diseases. In a series of seven consecutive fatal cases of bulbar poliomyelitis the major pathology was largely restricted to the reticular formation.[2,3]

SUMMARY

A clear-cut distinction can now be made between the two great systems of the forebrain: (i) the phylogenetically ancient *limbic complex* which is concerned with autonomic reactions involved in emotional expression and only secondarily with intellectual function, and (ii) the *somatic neocortex* which presides primarily over higher intellectual functions. Both systems are to be found in the anatomical frontal lobe. Lesions restricted to the frontal limbic system cause little or no impairment in intellectual functions such as visual discriminatory capacity, but such lesions do affect emotional behavior and to a limited extent such learned habits as those involved in double alternation.

The essential pathways to and from the limbic system pass in a discrete area in the medial ventral quadrant of the frontal lobe which can be interrupted in both animals and man by electrocoagulation. In one of Delgado's human subjects, intractable pain was dramatically relieved by a small bilateral lesion in this area, the relief having continued for an 18-month period. The gross intellectual deterioration that follows radical lobotomy is not seen with these small medial ventral lesions.

Other advances in neurophysiology in the past five years have led to a deeper understanding of spinal reflexes and their mode of operation in the human paraplegic. There has also been notable clarification of cerebellar function and of the functional activity of the reticular formation—all of which bids fair to increase our understanding of many obscure neurological disease entities, and through that knowledge to extend sound therapy, neurosurgical and otherwise.

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ON THE QUESTION AS TO THE EXISTENCE OF A "4s" SUPPRESSOR MECHANISM

EXPERIMENTS ON THE CAT AND HUMAN*

RUSSELL MEYERS, M.D., JOHN R. KNOTT, PH.D., F. MILES SKULTETY, M.D., AND ROBERT IMLER, M.D.

Division of Neurosurgery and the Department of Psychiatry, State University of Iowa, Iowa City, Iowa

(Received for publication September 28, 1953)

THIS paper reports observations on 34 humans and 6 cats in whom an attempt was made to demonstrate the presence or absence of "suppression" in (a) wakeful subjects, (b) subjects under general anesthesia, and (c) unanesthetized but unconscious (postictal) subjects. Cortical and subcortical structures were stimulated electrically and by strychnine and/or were extirpated. No "suppression" was noted.

DEFINITION

The phenomena of suppression are asserted to constitute a form of inhibition[1,22,23,25,28] having spatial and temporal characteristics by which they may be clearly distinguished from refractory period, extinction, decrement of fatigue and the reciprocal innervation of Sherrington.[7,8,28] They are assertedly mediated by certain narrow, well delineated bands of cerebral cortex, called 4s, 8s, 2 or 2s, 19 or 19s and 24.[16,17,26,27,42] It has recently been proposed that the posterior orbital gyri be added.[78] Among these, 4s has been the most intensively studied and findings relative to it have generally been regarded as the model for all other "suppressor areas."

The manifestations of "suppression" are describable under three headings as follows.

1. *Spasticity* conforming to Walshe's[85] criteria and following extirpation of a suppressor area.[21,34,35] (Actually this has been claimed only in connection with 4s.) 2. *Electrical suppression*, amounting virtually to isopotentiality of the prevailing electrical activity of the sensorimotor cortex (excepting only the suppressor area itself), following electrical or strychnine stimulation of a suppressor area.[47] 3. *Motor suppression* following electrical or strychnine stimulation of a suppressor area. This is exhibited as (a) diminution of muscle tension, i.e., resting or postural myotonus;[26,46,47] (b) reduction or abolition of the vigor of skeletal muscle contractions occurring spontaneously or induced by electrical stimulation of the "motor" cortex;[21,22,28,35,49,82] (c) elevation of

* Presented with motion picture illustrations at the meeting of the Harvey Cushing Society, April 23, 1953, Hollywood, Florida, under the title "Subcortical mechanism of motor suppression in the human: its non-dependence upon caudate nucleus, subcallosal fasciculus and anterior limb of internal capsule."

the threshold of excitability of the "motor" cortex;[22,28,47] (d) depression or abolition of after-discharge caused by electrical stimulation of the "motor" cortex,[28,46,47,82] and (e) depression of tendon[39,80,87] and corneal reflexes.[87]

Although more conspicuously contralateral, "electrical" and "motor" suppressions are said to occur bilaterally[35] and to exhibit a latency of from 4 seconds to 12 minutes, with an average of 4 minutes.[23,49] Latency is said to be influenced by (a) depth of anesthesia (the lighter, the shorter),[16,17,23] (b) type of stimulus (being shorter for electrical than for strychnine stimuli)[17,49] and (c) strength of stimulus (the stronger, the shorter).[49] Suppressor effects supposedly persist for 4 to 5 minutes or longer [16,17,23] and are incapable of reinstatement for periods up to 35 minutes.[16,17]

The process of suppression is said to be "clearly extrapyramidal . . . offering an approach to reciprocal innervation."[6,23,35,53] Because all muscles of paired sets, i.e. agonists and antagonists, are relaxed, such reciprocal innervation is conceived as existing between the pyramidal and extrapyramidal systems rather than as being Sherringtonian in nature.[16,17,22,25,35] Suppression is supposed to lend "easy initiation" to all voluntary movement.[35]

HISTORY

The notion that stimulation of parts of the frontal lobes might prevent or arrest movements consequent upon stimulation of the "motor" and "premotor" cortex or might raise the threshold of excitability of the monkey's "motor area" was advanced in 1919 by Vogt and Vogt.[84] The phenomenon was evidently again observed but not reported upon in 1934–1936 by Dusser de Barenne and McCulloch[15,19] and a similar observation was made in the decerebellate cat in 1935 by Rioch and Rosenblueth.[75] However, the first precise delineation of an anatomic region from which suppressor phenomena are elicitable was described in 1936 and 1937 by Hines.[34,35] She claimed that extirpation of a narrow strip of cortex between Areas 4 and 6 of the monkey resulted in spasticity without paresis or forced grasping and that its stimulation arrested cortically incited movements and relaxed the postural contraction of muscles. Her reports prompted Dusser de Barenne, Garol, McCulloch and associates to intensive investigations in the monkey, chimpanzee and cat. These workers employed not only electrical stimuli but technics of strychnine ("physiological") neuronography[14,20,21] and electrography of the cortex and subcortical structures. Incidental to their efforts to find the anatomic counterparts of suppression, they differentiated sharply between electrical and motor suppression and described independent paths for each.[18,21,23,47,49,51]

They and other authors[13,25,39,71,74,80,87] also reported the anterior cingulate cortex, Area 24, to be a powerful bilateral suppressor of electrical and motor activity in the monkey, cat and human. Hines[35] formulated the doctrine that *the normal function of the strip area is to inhibit the appearance of hypertonus*, especially extension, *clonus and brisk irradiating reflexes.*

In 1949, Kennard[42] hailed the discovery of suppressor mechanisms as

"the most significant alteration in current concepts of cortical interrelations" and said that although suppression had not as yet been verified by isolated ablation in man it is logical to suppose that it exists and will be found.

PHYSIOLOGIC FINDINGS

The following physiological observations have been recorded by various writers.

1. The type of spasticity "released" by *ablation* of Area 4s is essentially an exaggeration of the stretch reflex, characterized by the clasp-knife effect. It is maximal in the flexors of the elbow, extensors of the knee and adductors of the hip. All limbs are assertedly affected and bilateral removal gives permanent results. Paresis, if any, is slight and very transient. No grasp reflex appears. Contractures are slight.[34,35,54]

2. If to previous ablation of Area 6 ablation of 4s be added, the clasp-knife effect is lost and resistance to passive movement becomes virtually equal in agonistic-antagonistic pairs.[35]

3. If to previous ablation of Area 4, ablation of 4s be added, contractures become severe within 2 to 3 months, chiefly at the wrist and ankle,[35] but not in the digits.

4. Stimulation of 4s provokes no movements; on the contrary, it abolishes prevailing motor activity.[23,34,35]

5. After acute section of the medullary pyramids (="loss of the corticospinal tract"), stimulation of 4s continues to elicit relaxation of muscle tone.[35]

6. In the cortex, stimulation of 4s produces "spikes" in 4s only. It suppresses electrical potentials elsewhere in the sensorimotor cortex and in the lateral nuclei of the thalamus, bilaterally.[3,20,21,23] Spikes also appear in the caudate nucleus and bulbar reticular ("inhibitory") formation dorsomedial to the inferior olives.[20,23,50,51] They are not detectable in the putamen, globus pallidus or substantia nigra.[20,23]

7. A linear surgical section 12 mm. deep between 4s and 4 or a surgical "ring" encompassing 4s fails to abolish the effects described above: hence, they do not depend upon cortico-cortical connections.[20,23]

8. Subcortical undercutting deep to 4s abolishes the effects described in 6 above; hence, corticofugal fibers from 4s must be essential components of the suppressor mechanism.[20,23]

9. Stimulation of the caudate head suppresses electrical activity in both the thalamus and sensorimotor cortex, including Area 4.[20,23,49]

10. A surgical lesion ("pithing") in the caudate head interferes with the capacity of a stimulus applied to 4s to suppress electrical activity of 4. The larger the lesion the longer is the duration of such interference; hence, the caudate nucleus appears to be essential to electrical suppression. Lesions in the putamen, globus pallidus and substantia nigra do not block electrical suppression; hence, these structures must be unessential.[21,23]

11. Lesions of the caudate nucleus, putamen, globus pallidus, substantia nigra, corpus callosum, anterior commissure, medial thalamic nuclei and cerebellum do not prevent motor suppression; hence, these structures must be unessential.[21,23] (It should be remarked, however, that except for the cerebellum nothing like complete or discrete destruction of these nuclei has ever been reported.)

12. Lesions of the ventroposterolateral nuclei of the thalamus interfere with electrical, but not motor suppression.[49]

13. Stimulation of the ventroposterolateral nuclei of the thalamus electrically activates the sensorimotor cortex. However, antecedent interruption of thalamocortical radiations interferes with the phenomenon.[21]

14. Lesions of the lateral thalamic nuclei tend to "silence" the electrical potentials of the sensorimotor cortex.[20–22]

15. Stimulation of Area 4 or 6 does not produce "spikes" in the caudate nucleus, although the latter appear in other identifiable portions of the striopallidum.[16–18,21]

16. Surgical section of the midbrain peduncles prevents the appearance of "spikes" in the bulbar reticular formation after stimulation of 4s. Section of the medullary pyramids results in no such blocking.[50,52]

It should be remarked that the experiments summarized above were invariably implemented under general (Dial) anesthesia. Moreover, electrical and motor suppressor phenomena characteristically appeared only *hours* after exposure of the cortex —optimally, 18 or more, according to Gellhorn.[29–31]

17. If electrical stimulation of the striatum in the cat or monkey is imposed upon a background of posture or movement, muscular contraction "melts away."[24,56,61]

18. In the presence of spasticity consequent upon experimental cortical lesions, ablation of the striatum greatly augments the pre-existing hypertonus.[41,42,57–60]

ANATOMIC FINDINGS

The description of the locus of 4s set forth by Dusser de Barenne and McCulloch[21] is here quoted verbatim.

> Our 4s lies as a narrow band of cortex . . . extending from the posterior end of the arcuate sulcus (monkey) through the posterior portion of the precentral sulcus and continues onto the medial aspect of the hemisphere. No landmark on the surface corresponds to the anterior border of 4s. It measures 3 to 4 mm. wide at the top and 2 mm. at the bottom. . . . It resembles Hines' strip area.

Von Bonin[3] added that 4s is "mostly buried in the superior precentral sulcus." In the chimpanzee, however, the area is said to be wider and more readily accessible on the surface.[17,47]

The relevant microscopic data may be summarized as follows.

1. Area 4s is a part of the area frontalis agranularis, architectonically similar to Area 4 but having many fewer Betz cells.[34–37,40,44] It is distinguishable from Area 4 behind and 6 in front by "very large cells in the upper part of Layer IV."[3]

2. Fibers from Area 4 (in the inclusive sense used by older anatomists) have been assertedly traced in the monkey through the stratum zonale to the caudate nucleus.[38] Kennard[42] quoted Ramón y Cajal's finding of "collaterals" entering the basal ganglia from the adjacent internal capsule and Glees[32] assertedly extirpated the suppressor areas of the cat, following which he could trace non-myelinated fibers through the internal capsule to the putamen and caudate nucleus.

3. Mettler[55,56,60] described corticostriate fibers from the frontal lobes of the monkey and baboon which reach the neostriatum *via* the subcallosal fasciculus.

4. Using Marchi's stain after thermocoagulation of 4s in the monkey, Verhaart and Kennard[42,83] were unable to trace degenerating fibers into the caudate nucleus. However, they reported many such fibers coursing through the corticospinal tract to the level of the pons, whence they played out in the medial bulbar reticular for-

mation and medial longitudinal fasciculus. A. A. Ward[86,87] found a similar distribution of fibers derived from Area 24. No degenerating fibers were traced into the spinal cord.

5. In 1926, Papez[70] traced reticulospinal fibers from the bulbar reticular formation through the ventral and lateral funiculi of the cord to the internuncial pools about the anterior horns.

CONCEIVED PATHWAYS OF SUPPRESSION

Piecing the above data together, numerous authors[7,8,16–18,20–23,42,43,48–50,54] have proposed theories concerning the neural pathways involved in suppression. With minor modifications[3,69,86,87] these take the following forms.

Electrical suppression involves the suppressor areas; corticostriate fibers *via* the internal capsule and/or subcallosal fasciculus; various portions of the caudate nucleus (the head for 8s, 4s and 24, the body for 2s and the tail for 19); an as yet unidentified striatothalamic pathway[21] which probably passes through the globus pallidus and putamen; the ventroposterolateral nuclei of the thalamus; and the thalamocortical radiation to the sensorimotor cortex. *Motor suppression* involves the suppressor areas; corticofugal fibers which run with the pyramidal fibers through the internal capsule and pedunc les as far as the anterior pontine border, there to turn dorsally to end in the bulbar reticular feltwork and the medial longitudinal fasciculus; reticulospinal fibers to the internuncial pools of the spinal cord; and possibly a corticopetal "feedback" circuit arising from the bulbar reticular formation.

EVIDENCE OF SUPPRESSION IN THE HUMAN

In 1944 Garol and Bucy[28] claimed first demonstration of suppression in a human. Their patient was under light ether. They described a region just anterior to the left precentral gyrus and inferior to the posterior part of the superior frontal sulcus which, upon being stimulated, immediately inhibited the resting contraction of the contralateral upper limb and "greatly augmented" the threshold of excitability of Area 4. Presumably, this region is the counterpart of 4s in laboratory animals. Its suppressor effects were said to persist "for some minutes" after stimulation. Few quantitative data were cited and no studies of alterations in motor power, cortical electrical potentials, cortical after-discharge, deep-seated structures or deep and superficial reflexes were reported. The authors concluded, "Further studies must be conducted to determine the mechanism involved in the suppression of motor response and any possible relation of the corpus striatum to that phenomenon." Since then other cases of humans exhibiting phenomena interpreted as "suppression" have been observed[25,33,68,92] but thus far no report has been sufficiently cogent to convince the skeptically oriented.

Despite the conspicuously equivocal nature of currently available data, diagrams of the human brain have appeared in which Area 4s is depicted[2,4] by mosaic devices in precisely the same manner as that used to represent the "motor" (Area 4) and visual (Area 17) cortex. Recent textbooks of

human neuroanatomy[3,5,76] describe the 4s region in the human with much the same confidence as that used for the red nucleus and inferior olives.

THEORETICAL NEUROLOGY AND CLINICAL APPLICATIONS

The advent of the concept of suppression has prompted the development of several hypotheses concerning the pathogenesis of perplexing clinical neurological disorders. The earliest and best known of these are Bucy's theories of paralysis agitans and choreo-athetosis.[7,8] A similar theory of hemiballism was ventured by the present writer[63,67] in 1949. In addition, after plotting out the sites of brain perforation in 138 cases of head wounds followed by epilepsy and 228 patients free of seizures, Russell[77] tentatively suggested that damage to the suppressor areas might predispose to epilepsy. He recommended further intensive pursuit of the problem.

Such theories have, of course, inevitable practical consequences. Wyke,[92] for example, performed numerous operations for parkinsonism by subcortical linear section of U-fibers anterior to 4s. The procedure appears by now to have been abandoned. Bucy[7,8] expressed the conviction that to be effective for the abolition of tremor surgical procedures must largely interrupt at some level the pyramidal tract, hence must entail considerable pyramidal deficit. If his concept is correct, a matter as yet unresolved,[63,65,66] certain limitations as to the selection of surgical candidates and prognosis inevitably follow.

CONTRARY DATA

As noted above, virtually all physiological findings referable to electrical and motor suppression have been reached under the compromising conditions of general anesthesia, sometimes only after long exposure of the brain. In 1948–1950, G. Clark and J. Ward,[9,10] J. Ward[89] and others reported failure to observe "anything resembling suppression" in unanesthetized monkeys and dogs in whom implanted electrodes were used. (Their studies were confined to "motor" suppression.) J. Ward[90] later wrote that he had never seen any evidence of suppression or inhibition of motor activity from stimulation of the caudate nucleus in the monkey or cat.

In 1950, Penfield and Rasmussen,[72,73] employing unanesthetized human subjects, remarked in passing, "Stimulation has in our hands cast no light upon the existence of a repressor strip, 4s of Marion Hines. . . . " Their observations did not, however, extend to subcortical structures.

In a critical review of the whole subject up to 1952 and as a result of independent study in a series of cats, Druckman[12] failed to find support for the prevailing notions of "suppressor strips" and "suppression."

As to the effects of extirpation, Mettler and Pool[62] reported negative results upon removal of "the rostral portion" of Area 4 in a human. It is not, however, certain that the tissue Pool removed corresponds topographically to that described by Garol and Bucy[28] and depicted in von Bonin's diagram.[2]

Reports on extirpations and/or undercutting of the anterior cingulate region in the human now amount to over 110 cases.[11,45,79,91] In none of these was spasticity or hyperkinetic "release" reported. Similar remarks hold in the case of monkeys from whom Area 24 has been removed.[80,81,86,88] In one of A. A. Ward's monkeys, all 5 suppressor strips were claimed to have been ablated. The animal became "tame" but apparently exhibited neither spasticity nor hyperkinesia.

Whitty *et al.*[91] stimulated Area 24 in a small series of humans without producing any signs of "motor" suppression.

Thus, a small but stubborn body of negative data precludes as of the present tacit acceptance of the suppressor strip doctrine.

THE PROBLEM

The question now arises as to whether suppression represents a mechanism of inhibition that plays a regular role in the wakeful subject or a mere artefact of the differential effects of certain anesthetic agents[10] or of other adverse conditions imposed upon the organism by the experiment itself. Up to the present no attempts to deal directly with these questions and their corollaries concerning the subcortical mechanism(s) of suppression in the human have been reported. The present writers accordingly attempted to answer the following:

(1) Can *ablational*, *electrical* and/or *motor* suppression be demonstrated *in re* "Area 4s" in the human? (2) If so, what influence, if any, does general anesthesia or "unconsciousness" not caused by anesthesia exert *in re* the readiness with which *electrical* and *motor* suppression can be demonstrated? (3) What subcortical roles, if any, are played by the caudate nucleus, anterior limb of internal capsule and subcallosal fasciculus?

METHODS AND MATERIALS

Data were sought from two sources: (1) *stimulation* by electric current and/or strychnine and (2) *surgical extirpation* at cortical and subcortical levels.

1. *Stimulation Studies in the Human.* After wide exposure of the hemisphere of one or both sides from the superior temporal gyrus laterally to the falx medially and from a coronal plane approximately 3 cm. behind the frontal pole anteriorly to a plane corresponding to the posterior crus of the supramarginal gyrus posteriorly, control observations were made with reference to (a) *postural set* of the upper limb(s) in repose; (b) briskness of *deep reflexes;* (c) *motor power* as measured dynamometrically in the 6 patients under local anesthesia; and (d) simultaneous *electrocorticography* at 9 or more representative cortical sites, using spring-equipped silver ball pick-up electrodes set in a Marshall carriage fixed to the skull. The "motor" cortex (Area 4γ) corresponding to the digits, hand and forearm of the contralateral upper limb was delineated by means of bipolar Ag electrodes 3 mm. apart. Parameters were 50 *or* 60 cps, biphasic saw-tooth and/*or* sinusoidal waves, pulse duration 2 *or* 5 ms and stimulus duration 4 to 5 sec. (approx.). When, after several repetitions, the threshold value had been ascertained, the stimulus strength was increased

slightly (approx. $\frac{1}{4}$v) to offset the effects of small "spontaneous" variations in excitability. Intervals of 2 to 5 min., sufficient to permit subsidence of facilitation and extinction, were allowed between successive stimuli.[93] Representative regions of the remainder of the exposed cortex were next explored at slightly-above-threshold values to determine whether subjective or objective responses were elicitable. None was.

It was soon found desirable to regulate the voltage as delivered to the tissue (in contrast to dial readings) by interposing a cathode ray oscilloscope between the stimulator and the stimulating electrodes. Such was employed in the final 5 humans of the series (in whom the most satisfactory experimental conditions obtained) and in the cat series.

The "motor" cortex ("4γ") having been thus delineated, "4s" was grossly envisioned in accord with landmarks previously described.[2,7,8,17,21,28,47,68] The "4s" strip was then minutely explored with stimulating electrodes delivering physical energies more than double those of the threshold values of the "motor" cortex. In addition, the cortex adjacent to "4s" was explored for fully 1 cm. beyond its envisioned anterior and posterior margins, by which means it was hoped to "cover" individual anatomic variations of "4s."

Cortical potentials including induced after-discharges were recorded in all experiments by an ink-writing Model III Grass EEG. The operative team and observers were kept intact.

The effectiveness of stimuli on postural set, muscle "tonus" (as estimated by the flail test), biceps humerus reflexes and "volitional" motor power (dynamometrically recorded) were repeatedly made and compared with "control" performances.

Data were first acquired under conditions of electrical stimulation, after which comparable data were acquired under conditions of stimulation by 3 per cent strychnine phosphate applied to the "4s" strip by moistening a 4×10 mm. piece of filter paper and adopting precautions against diffusion of the strychnine as recommended by Dusser de Barenne *et al.* In one case (M.J.) strychnine was also applied by intracortical injection of 0.3 mm. into the anterior bank of "4s."

In the next phase of inquiry the head and body of the caudate nucleus were exposed to direct vision through a 3 cm. corticotranscallosal incision running in a sagittal plane 2 cm. from the midline near the anterior margin of the operative field. A slender insulated shaft bearing 4 silver-ring pick-up electrodes each 0.5 cm. from its neighbor(s) was inserted into the posterior half of the caudate head and fixed *in situ* (Fig. 1).

"Control" procedures were now repeated in the order above described, following which electrical stimulation of "4γ" and electrical and strychnine stimulations of "4s" were carried out. In this way electrocaudatography was performed simultaneously with electrocorticography.

The posterior half of the caudate nucleus was then stimulated (a) electrically with the same or "stronger" parameters than those employed on "4s" and (b) by strychnine applied by filter paper on its ependymal surface and/or injected in quantities of 0.2 to 1.4 ml. close to the pick-up electrodes.

All crucial observations were continued for periods of 15 to 25 min. before new stimuli were employed. The purpose of this was to allow ample time for latency of suppression to pass off.

The subjects studied were patients undergoing open psychosurgery (standard lobotomy, cingulectomy) for major psychoses or lobotomy for

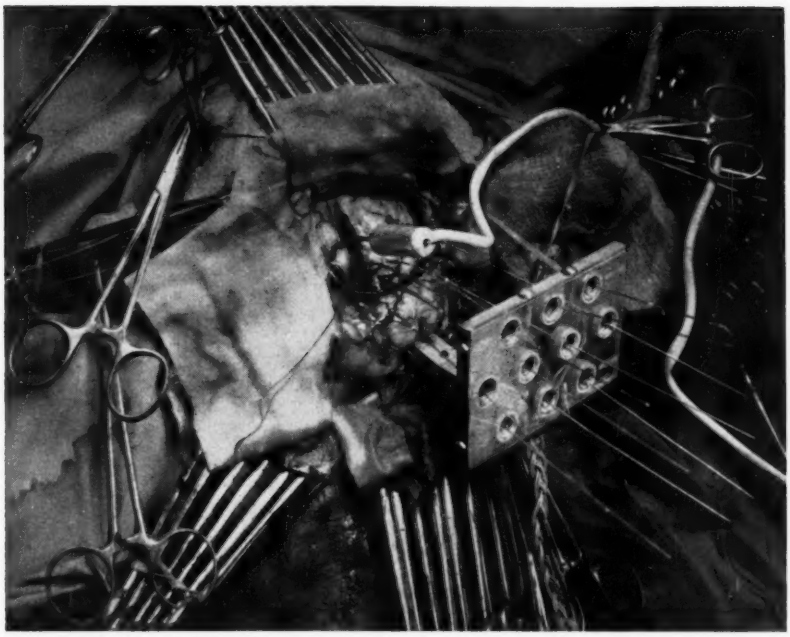

FIG. 1. Experimental set-up, patient L.B., showing right hemisphere exposed with cortical pick-up electrodes *in situ* and Marshall carriage fixed to edge of skull. An incision may be seen in the anterior frontal cortex through which deep pick-up electrodes have been inserted under direct vision into the head of the caudate nucleus.

intractable pain. The studies described above were always completed before the intended therapeutic surgical maneuvers were executed. In all, 10 such studies were performed, 6 on patients during "local" (1 per cent procaine HCl), and 4 during light ether anesthesia without preliminary medication. Attention was directed at keeping the "level" of anesthesia as constant as modern facilities permit (Table 1).

TABLE 1

Patient, Age, Sex	Diagnosis	Anesthesia	Threshold 4	Stimulus to "4s"	Stimulus to Caudate
F.C., 39 yr. F	Schizophr. Cat.	Local	2.5v	5v, 12 s	5v, 12 s
W.S., 38 yr. F	Schizophr. Par.	Local	1.75v	4–6v, 15 s	4v, 15 s
R.G., 22 yr. M	Schizophr. Heb.	Local	3.25v	7.0v, 15 s	7.0v, 15 s
G.S., 45 yr. F	Manic-Depr.	Ether	5.8v	13v, 14 s	13v, 20 s
A.H., 44 yr. F	Schizophr. Mix.	Ether	4.25v	9–14v, 20 s	9v, 20 s
L.B., 32 yr. F	Schizophr. Heb.	Local	2.5v	5v, 15 s	5v, 15 s
W.M., 31 yr. M	Schizophr. Heb.	Ether	4.0v	9–12v, 20 s	8.5v, 22 s
M.J., 61 yr. F	Intract. Pain	Local	3.0v	7v, 12 s	Strychn. only
P.W., 38 yr. F	Schizophr. Heb.	Local	0.9v	3v, 14 s	3v, 14 s
G.K., 44 yr. F	Manic-Depr.	Ether	3.5v	6–8 v, 5 s	Strychn. only

In 4 cases the design of experiment was fully realized. In 4 others it fell somewhat short of full realization but was still satisfactory. In the 2 remaining, observations had to be curtailed before satisfactory execution of experimental design because of the development of instrumental defects, uncooperativeness on the part of the patient and/or inadvertent seizures. Even in these instances, however, some informative data were acquired.

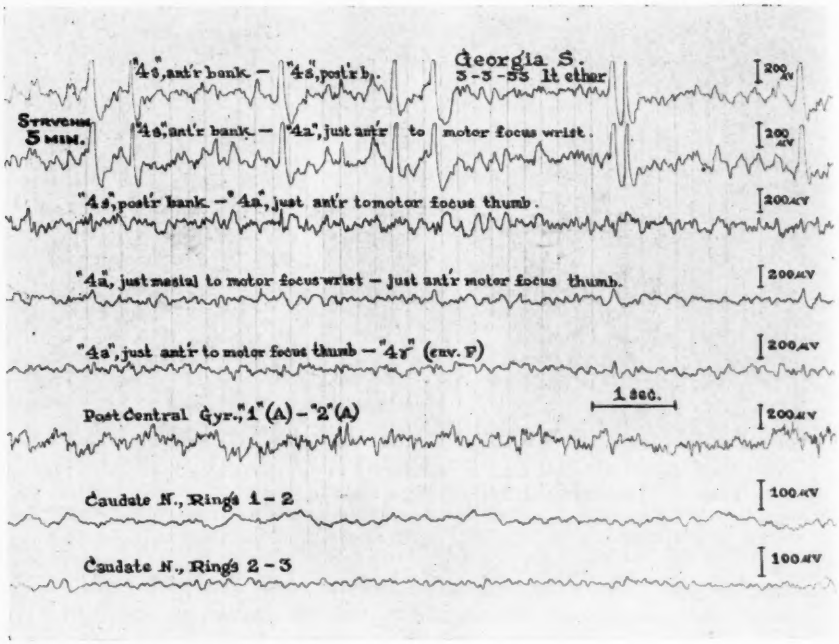
Georgia S.
3-3-55 lt ether
Strychnine 5 min.
"4s", ant'r bank — "4s", post'r b.
"4s", ant'r bank — "4a", just ant'r to motor focus wrist.
"4s", post'r bank — "4a", just ant'r to motor focus thumb.
"4a", just mesial to motor focus wrist — just ant'r motor focus thumb.
"4a", just ant'r to motor focus thumb — "4r" (env. F)
Post Central Gyr., "1" (A) - "2" (A)
1 sec.
Caudate N., Rings 1 - 2
Caudate N., Rings 2 - 3
200 μV
100 μV

FIG. 2. Electrocorticography and electrocaudatography 5 minutes after application of strychnine phosphate 3 per cent to Area "4s," showing spikes in "4s" with no evoked spikes or other potentials in the caudate nucleus and no evidence of electrical suppression in other regions of the sensorimotor cortex. The recordings were continued for 25 minutes without essential change. This patient, G.S., was under light ether anesthesia. Similar recordings were obtained in patients under local anesthesia only.

Results. Despite the appearance of recordable after-discharges and good "spikes" at "4s" and/or the caudate head,

(1) no reduction in electrical potentials of the sensorimotor cortex was observed (Fig. 2); (2) no elevation or other alteration of threshold of excitability of the "motor" cortex "4γ" was observed; (3) no obliteration of after-discharges in "4γ" or "4a" was observed; (4) no alterations in biceps jerk, "volitional" motor power, "muscle tonus" or postural set were observed beyond trial-by-trial variations demonstrated in the "control" periods; and (5) following adequate stimulation of "4s," no spikes or other signs of evoked electrical activity were recorded in the caudate head (Fig. 3).

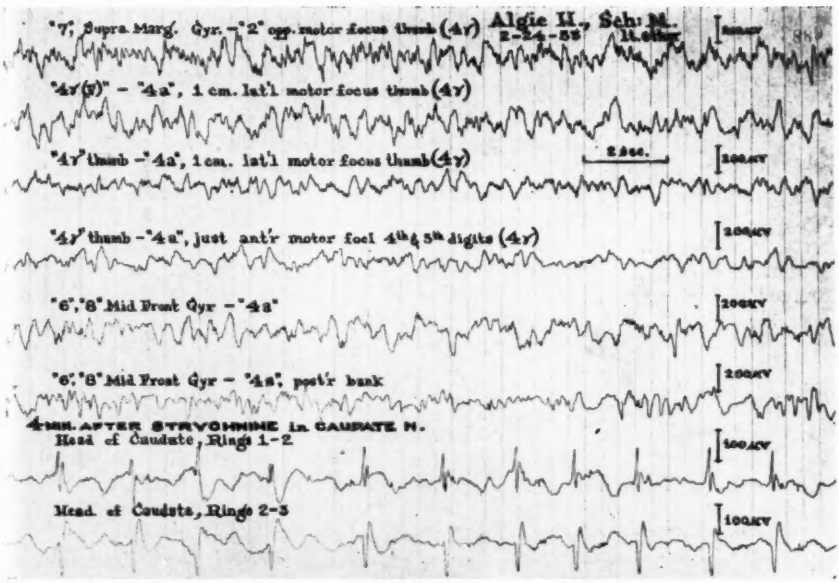
"7", Supra Marg. Gyr. – "2" opp. motor focus thumb (4γ)
Algie H., Sch: M.
2-24-55
"4γ(3)" – "4s", 1 cm. lat'l motor focus thumb (4γ)
"4γ" thumb – "4s", 1 cm. lat'l motor focus thumb (4γ)
2 sec.
"4γ" thumb – "4s", just ant'r motor foci 4th & 5th digits (4γ)
"6", "8" Mid Front Gyr – "4s"
"6", "8" Mid Front Gyr – "4s", post'r bank
4 MIN. AFTER STRYCHNINE in CAUDATE N.
Head of Caudate, Rings 1-2
Head of Caudate, Rings 2-3

FIG. 3. Electrocorticography and electrocaudatography 4 minutes after injection of 0.3 ml. strychnine phosphate 3 per cent into head of caudate nucleus, near deep pick-up electrodes, showing spikes in caudate head but no electrical suppression of the sensorimotor cortex. The recordings continued essentially unchanged during 20 minutes. This patient, A.H., was under light ether anesthesia. Similar recordings were obtained in patients under local anesthesia only.

2. *Extirpation Studies in the Human.* Two regions were subjected to extirpation, superficial and deep. In the former, the region of cortex envisioned as "4s" was ablated by subpial technic. The defect measured approximately 1×4 cm. and involved the anterior and posterior banks of the precentral sulcus down to and including the depths. The proximate "shoulders" of the gyri on each side of the sulcus were also ablated. The defect lay rostral to the excitable "motor" cortex of the contralateral limb and corresponded to the diagrams offered by Garol and Bucy[28] and von Bonin.[2]

Such extirpations were performed in 4 adult subjects. Of these, 1 (G.K.) was a member of the stimulation-series above described. The others consisted of 2 females, B.B., 32 years, manic-depressive, and F.P., 51 years, hebephrenic, and 1 male, C.J., 64 years, paranoid.

Following operation, neurologic examinations were performed daily for 2 weeks and thereafter at intervals of 4 to 10 days for 3 months, seeking evidences of (a) spasticity, as defined by Hines,[35] Magoun[54] and Walshe[85] and (b) other "release" phenomena, e.g., hyperkinesia.

Results. In no case were spasticity, hyperreflexia, or "upper motor neuron" signs apparent, even during the first few days postoperatively when a more diffuse compromise of cerebral function beyond the confines of ablation might be presumed to prevail. Two patients showed a transient, slight

paresis and dyspraxia which lasted for no more than 5 days; the others showed none.

The deep extirpations were performed on 20 adults, 19 of whom were suffering from parkinsonism or non-patterned hyperkinesias and one of whom was schizophrenic. The latter, R.G., was also a member of the stimulation-series above described. The remainder have been referred to in previous articles.[64,65] In all, the head and body of the caudate nucleus as far posteriorly as the genu of the internal capsule were ablated and the anterior limb of the internal capsule and subcallosal fasciculus were sectioned in linear fashion. Postoperative clinical neurological and cinematographic studies were made, seeking (a) spasticity and (b) other signs of "release" as defined above.[35,54,85] The average period of intensive postoperative examinations was 6 weeks.

Results. No evidences of spasticity, hyperreflexia or "upper motor neuron signs" were observed.

3. *Suppression Studies in the Cat.* Six cats were subjected to electrical and strychnine stimulations of the several suppressor regions described by Garol.[26,27] Anesthesia consisted of Dial, 0.45 ml/K, one-half by peritoneal sac, one-half by muscle.

The "motor" cortex was first identified by stimulating electrodes after which pick-up electrodes were placed on representative regions of the hemispheral convexities, bilaterally. After suitable control periods, stimulation was begun, first electrically and then by strychnine.

The procedure followed closely that described by Garol and, in addition, electrical stimuli well above the maxima used in our own human experiments and capable of producing strong electrical after-discharge were employed. One animal, cat 4, exhibited "spontaneous" rhythmic stepping movements of the forelimbs throughout the control and experimental periods of observation and thus afforded an especially favorable opportunity to study "motor" as well as "electrical" suppression (Fig. 4).

After each electrical stimulation, periods of 20 to 25 min. elapsed before a new stimulus was applied and when strychnine was employed the filter paper was removed as soon as "spikes" appeared and observations were prolonged for 20 to 25 min. as with the electrical stimuli. In no case was a new area stimulated until the spikes of a previously stimulated area had subsided.

Results. No instance of electrical or motor suppression was recorded.

DISCUSSION

Additional evidence that extirpation and undercutting of a "powerful" suppressor area, namely, the anterior cingulate gyrus, are not followed by spasticity or other "release" phenomena is discovered in the reports of Whitty *et al.*,[91] Scoville[79] and Cleveland.[11] These observations, those of Kennard[41] and our own are difficult to reconcile with the sweeping assertion[43] that "Lesions of any part of the suppressor system, cortex, caudate nucleus, anterior lobe of the cerebellum, fastigial nuclei and medial reticular formation

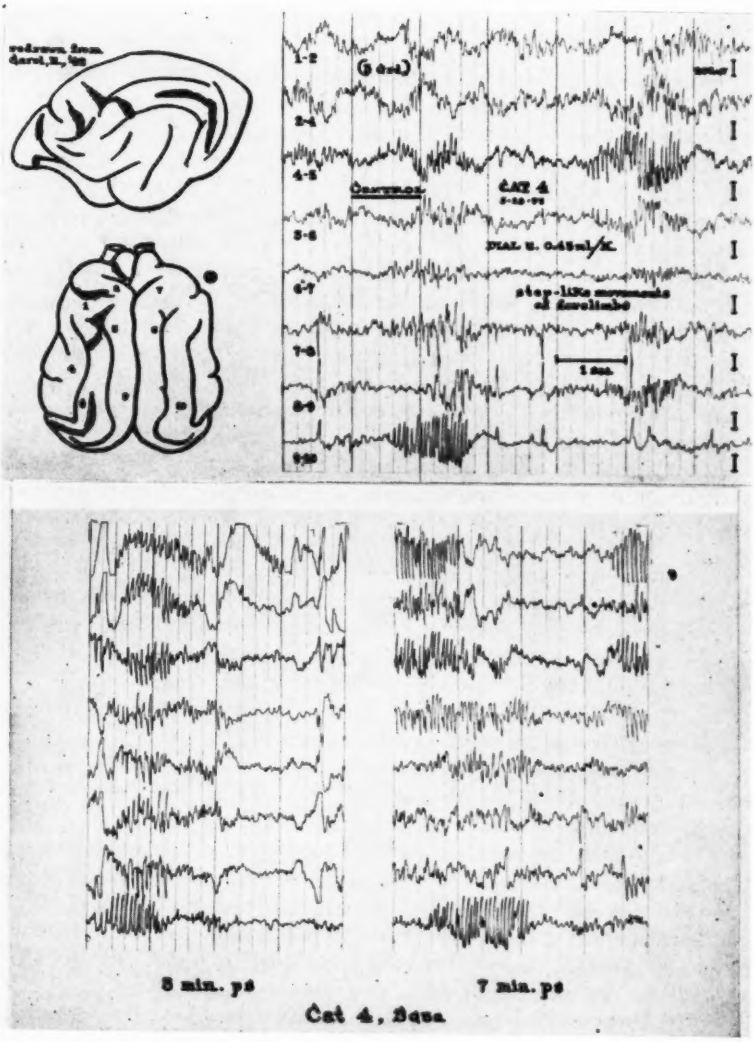

FIG. 4. (*Above*) Electrocorticography, Cat 4, during control period and (*below*) 3 and 7 minutes respectively following electrical stimulation of a suppressor area using biphasic 50 cps saw-tooth waves 10v, 5 ms pulses for 7 seconds. The bursts of high potentials corresponded to rhythmic spontaneous step-like movements. Neither these skeletal movements nor the electrical potentials of the animal's hemispheral convexities were suppressed by stimuli applied to each of the several suppressor areas described by Garol.[26] Recordings were made continuously for 25 minutes following each stimulus. Similar results were obtained following strychnine stimulation.

will result in spasticity . . . ," especially when no empirical evidence for such is offered.

Our data thus far have given uniformly *negative* results *in re* electrical and motor suppression in the anesthetized, non-anesthetized and "unconscious" subject. Such does not, of course, prove that suppression does not occur; it indicates only that until unequivocal evidence is brought forward skepticism of the concept is warranted. Above all, it suggests that pathogenetic concepts in which "suppression" is made an essential component and therapeutic measures "rationally" fashioned on such bases must remain suspect. This agnostic position can and should be promptly revised *if* sound evidence to the contrary should in the future be adduced.

One would be inexcusably rash to imply that previous workers responsible for the current concept of suppressor strips were in error. Their findings might very well hold *for the conditions of experiment employed*, i.e., general anesthesia, long hours of exposure, cooling and drying of the cortex, the discounting of "negative" results etc., and as such may merit further inquiry in consideration of the differential effects of noxious agents. But this is a wholly different matter from acting on the assumption that "suppression" constitutes a normally active mode of inhibition. Here our case rests.

SUMMARY

1. Ten human subjects, 4 under general and 6 under local anesthesia, were studied electrographically at cortical and neostriatal levels under conditions of electrical and strychnine stimulation to determine whether "electrical" suppression from "Area 4s" is demonstrable. None was.

2. Similar studies concerned with "motor" suppression were implemented on the same subjects, again with negative results.

3. Four humans were subjected to extirpation of "Area 4s." Extended postoperative studies failed to disclose "release" of spasticity or hyperkinetic phenomena.

4. Twenty humans were subjected to extirpation of the caudate head and body, anterior limb of the internal capsule and subcallosal fasciculus. Postoperative studies failed to disclose spasticity or hyperkinesia.

5. Six cats under general anesthesia were subjected to stimulation of the "suppressor" areas by electrical and strychnine devices. No evidence of "electrical" or "motor" suppression was apparent.

6. Until more unequivocal data are adduced, cautious reservation as to the validity of the concepts of suppression and suppressor strips is in order. These concepts ought not lightly be employed in fashioning pathogenetic theories of hyperkinetic disorders, spasticity and epilepsy nor made the essential basis of "rational" modes of therapy.

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THE NON-SPECIFIC THALAMOCORTICAL PROJECTION SYSTEM*

JOHN HANBERY, M.D., AND HERBERT JASPER, M.D.
Department of Neurology and Neurosurgery, McGill University, and the Montreal Neurological Institute, Montreal, Canada

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THERE are two principal thalamocortical projection systems, the specific and the non-specific. The specific system is composed of the five relay and two association nuclei of the thalamus with their direct pathways to restricted cortical areas. Thus the lateral and medial geniculate bodies project only to the visual and auditory areas, the sensory relay nuclei to the somatosensory region; the anterior nuclei relay impulses from the mammillothalamic tract to the cingulate area, and the nucleus ventralis lateralis projects directly to the motor cortex after receiving fibers from the dentato-rubro-thalamic tract. The two association nuclei are medialis dorsalis with its connections to frontal cortex and the lateralis posterior-pulvinar complex projecting to the parietal region. It is universally accepted that these specific nuclei have direct thalamocortical fibers and when these localized areas of the cortex are ablated the cells of the corresponding thalamic nuclei undergo retrograde degeneration. If one inserts a stimulating electrode into one of the specific nuclei and records from the surface of the cortex, the responses obtained show very characteristic features. There is a very short latency wave form which can be recorded only from a discrete area of the cortex. The stimulus threshold is of low voltage and short pulse duration. Responses can be easily obtained with a single shock and they can also follow high frequency stimulation.

The non-specific thalamocortical projection system refers to the widespread cortical responses obtained on stimulation of centrum medianum, midline and intralaminar nuclei, ventralis medialis, ventralis anterior and reticularis. In general these responses have a higher stimulus threshold and require repetitive stimulation at 5 to 8 per sec. in order to show the characteristic "recruiting response." The wave forms differ from those obtained from the specific nuclei and have a much longer latency, usually from 10 to 40 msec. In the cat, the cortical responses are usually most easily obtained, and remain the most constant, from the anterior head regions in frontal and motor cortices. However, excellent responses can also be recorded from the anterior cingulate area, the parietal cortex, and the sensory, visual and auditory areas. The pattern of cortical responses varies with different points of stimulation within the diffuse thalamic nuclei. Widespread responses can be more readily obtained on stimulating the anterior portion of this system in ventralis anterior and the oral pole of reticularis, where the stimulus threshold is lower and the latency of the responses is shorter than in the remainder of the non-specific nuclei.

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From our physiological data, it would seem that the specific and non-specific systems are independent of each other. An anatomical pathway from the non-specific thalamic nuclei to the cortex has never been clearly demonstrated. It has been suggested that these widespread cortical responses are carried over diffuse but direct thalamocortical fibers, relayed through the nucleus reticularis, transmitted through the caudate nucleus, or projected directly to rhinencephalic areas where they are re-distributed to the other neocortical regions. Since many workers have felt that none of the non-specific nuclei show significant retrograde degeneration following decortication, some have recently suggested an intrathalamic diffusion system from which non-specific impulses are relayed via the specific thalamic nuclei to the cortex over well recognized direct pathways.

In order to clarify this point, we have recently studied the effect of specific nuclear destruction. In a series of experiments in the cat, each of the specific thalamic relay and association nuclei have been destroyed by electrolytic lesions, and in each case non-specific responses could still be recorded from the topographically related cortical area.

When one stimulates within the posterior portion of the non-specific nuclei, for example in centrum medianum, and records from the anterior portion of this system within the thalamus, responses can be obtained and followed through ventralis medialis, ventralis anterior, through the oral pole of reticularis, and out into the anterior limb of the internal capsule. These intrathalamic responses have a shorter latency than the recorded cortical potentials. We have more recently made much smaller thalamic lesions within this very active portion of the non-specific system situated at the oral pole of the thalamus and have observed the disappearance of the cortical responses initiated by stimulation farther posteriorly within centrum medianum.

During the past few years, it has become apparent that this non-specific thalamocortical projection system occupies a major position within the functional organization of the central nervous system. It has been shown to have collateral connections with incoming somatosensory, visual, auditory, splanchnic and cerebellar responses ascending through the brain stem, to be related to the hypothalamus, striatum, rhinencephalon, and specific thalamic nuclei, and to have diffuse connections both to and from the neocortex. Its inherent rhythmicity of discharge has been suggested as a regulating mechanism in the spontaneous activity of the cortex. It is thought to play a dominant role in the integration of neural activity, and has been related to such phenomena as consciousness, sleep, attention, idiopathic epilepsy, and frontal lobe function.

The exact thalamocortical pathway for the diffuse system remains unknown. As the result of our experiments, however, we have felt that these widespread cortical responses either passed through the oral pole of the thalamus or depended upon the integrity of the neurones within the anteriormost portion of the diffuse thalamic nuclei, and that the responses were not mediated through any portion of the specific projection systems.

DISCUSSION*

PAUL C. BUCY†
Chicago, Illinois

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IN RECENT years several investigators have expressed doubts as to the existence of the cerebral cortical suppressor bands of Dusser de Barenne. Judicious consideration of this problem requires a dispassionate analysis of all the facts. Obviously differences of opinion have arisen here because investigative techniques and experimental animals have differed. The issue has also been clouded by unprofitable quibbling over terminology. It must be apparent to all that the physiological and clinical facts are not influenced by whether one prefers to use the term "suppressor," "repressor" or "inhibitory."

No one rightly can question the existence of the suppressor bands of Dusser de Barenne unless he duplicates the experiments of Dusser de Barenne and his associates, McCulloch, Bailey, Garol and others. Dusser de Barenne carefully defined a certain type of electrical effect which occurred in subhuman primates under certain definite anesthetic agents when strychnine was applied to the cerebral cortex in a certain specific fashion. In this way he and his successors repeatedly demonstrated a series of "suppressor" bands in the cerebral cortex which suppressed the electrical activity of other parts of the cerebral cortex when strychnine was applied to the surface of these cortical bands. They also developed evidence that this effect was exerted through the caudate nucleus.

Obviously the failure to demonstrate this effect when other animals or different anesthetic agents are used or when the cortex is excited by an electrical current in no way invalidates the observations of Dusser de Barenne and his associates. So far as I am aware no one who has questioned the existence of the suppressor bands has attempted to check the original observations.

In considering the suppressor strips, particularly the strip known as 4s, it must be borne in mind that two activities have been ascribed to it. One is the suppression of cortical electrical activity, just mentioned. The second is the suppression or inhibition of peripheral motor responses (postural reflexes, spasticity, movements induced by cortical stimulation and spontaneous movements). This latter effect is not dependent upon transmission through the caudate nucleus nor does it require that that structure be intact.

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† 25 East Washington Street, Chicago 2, Illinois.

The existence of this second suppressor or inhibitory effect is supported by the observations of various investigators and by other indirect evidence. Fulton pointed out that the inhibition of postural reflexes is, so far as the precentral cortex is concerned, largely a function of the extrapyramidal systems. This fact was supported by the observations of Tower upon animals whose pyramidal tracts had been destroyed in the medullary pyramids. However, it was not known which of the many cortical extrapyramidal systems was concerned in this inhibition of peripheral motor activity until Hines demonstrated that the "strip" (later designated 4s by others) was the portion of the agranular precentral cortex so concerned. Hines demonstrated that at when the area 4s was removed spasticity developed in the contralateral extremities, whereas when this strip was stimulated both "standing" and "flexor tone" were relaxed. McCulloch and his collaborators demonstrated that at the fibers descending from the strip 4s terminate in the reticular formation of the bulb. Magoun and Rhines, in turn, showed that the reticulospinal connections descending from this bulbar reticular formation are very active in the inhibition of the postural reflexes. "When this bulbar reticular area was stimulated in decerebrate animals, their rigidly extended legs lost all tone and became flail-like to manipulation." Furthermore, this same system was capable of inhibiting movements evoked by stimulation of the precentral area. Thus we have clear-cut evidence, none of which has ever been disproved, that the strip 4s is capable of inhibiting peripheral muscular activity; that the strip 4s is directly connected with the bulbar reticular formation; and that this latter is, in turn, also capable of inhibiting peripheral muscular activity. This leaves little doubt regarding the inhibitory functions of area 4s in subhuman primates.

The evidence regarding the existence of area 4s in man and its functions is much less complete and much less conclusive. Garol and I demonstrated that by stimulation of a small area of cortex in the region of the precentral fissure we could cause prompt relaxation of the rigidity of contralateral extremities induced by light ether anesthesia, and, after a latency of 5 to 10 sec., an abrupt cessation of the motor after-discharge produced by stimulation of the precentral gyrus. In the instance reported this effect could not be elicited from any other area of the exposed cortex. Since then we have made similar observations in other patients and other observers have confirmed our findings. However, the areas from which we have obtained such effects have always been relatively small areas along the precentral fissure. They have never been "strips" of cortex comparable to those demonstrated by Hines or Dusser de Barenne and McCulloch in the monkey. Obviously these observations are too few, too limited and too poorly controlled to be of any great significance in themselves. They are of value only insofar as they corroborate and support the more detailed observations made in laboratory animals. Nevertheless, such positive observations as these are not refuted by the negative ones reported by Penfield and now by Meyers. The difficulties and the inconstancies of electrical stimulation of the human

cerebral cortex are too great to allow much significance to be attached to the failure of any observer to obtain such effects.

Penfield has demonstrated "inhibition of voluntary movement" from stimulation of a secondary motor area in the lowermost part of the precentral gyrus just above the Sylvian fissure; and further commented that, "arrest of movement instead of initiation of movement is not unusual as the result of stimulation within the primary motor areas also." Whether this "inhibition of voluntary movement" is related to the arrest of reflex muscular activity produced by stimulation of area 4s and other suppressor strips one can not say, but the two are certainly not exactly the same thing.

It must not be lost sight of that what we are discussing here is the experimental demonstration of the suppressor strips and how they behave under experimental conditions. How they behave in the intact animal or in man; what part they play in normal physiology or in clinical neurology is a matter for study and interpretation. Unfortunately, the effects of artificial stimulation of the brain are far too limited, too crude, too dependent upon the state of the animal, the anesthetic agent used, the nature of the stimulation, and upon the frequency and intensity of stimulation to be comparable to normal nervous activity. Much as we may be tempted to do so we cannot directly interpret the results of artificial stimulation in terms of the normal or abnormal activity of the nervous system of the intact laboratory animal and far less that of man.

THE LIMBIC SYSTEM AND ITS HIPPOCAMPAL FORMATION

STUDIES IN ANIMALS AND THEIR POSSIBLE APPLICATION TO MAN*

PAUL D. MacLEAN, M.D.

Departments of Psychiatry and Physiology, Yale University School of Medicine, New Haven, Connecticut

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TODAY with the annual celebration of Shakespeare's birthday, it may be expected that the occasion will arouse renewed discussion among those interested in English literature as to whether Shakespeare or Bacon wrote the plays. This points up for contrast an equally bewildering problem that faces those whose major concern is with the functions of the brain. In the brain, the authors of function—the structures themselves—are easily identified. But what do these authors write? That is the question. This is no better illustrated than by our lack of knowledge regarding the functions of parts of the limbic system that will concern us here, particularly that sizeable author known alternatively as the hippocampus or Ammon's horn.

The limbic system is comprised of the great limbic lobe of Broca and its subcortical cell stations.[47] The limbic lobe, including the infolded hippocampus, was so named by Broca[6] because it completely surrounds the hilus of the hemisphere. Its subcortical cell stations include the amygdala, septal nuclei, the hypothalamus, anterior thalamic nuclei, parts of the basal ganglia and perhaps also the epithalamus. In Fig. 1, in which the brains of the rabbit, cat, and monkey are drawn roughly to scale, the limbic lobe is represented in black. The drawings illustrate, as Broca pointed out, that the limbic lobe forms a common denominator in the brains of all mammals. In accordance with the theory of Papez,[55] the experimentation of the last fifteen years suggests that the limbic lobe also provides a cortical common denominator for a variety of emotional and viscerosomatic reactions in the mammal.† Its constancy of gross and microscopic structure throughout the phylogeny of the mammal contrasts strikingly with the mushrooming neopallium which surrounds it and is shown in white in Fig. 1. The latter, some might

* The substance of this paper, including all but the second and last figures, was presented at the meeting of the Harvey Cushing Society, Hollywood, Florida, April 23, 1953. Some material has been added from a paper that was given at a special session on the physiology of emotion which was held in conjunction with the International Physiological Congress, Montreal, Canada, September 2, 1953.

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† Several reviews and papers pertaining to this subject have appeared since 1947, a number of which are cited in the references.[7,10,18,21,31,32,45,71]

argue, could be likened to an expanding numerator representing in phylogeny the growth of intellectual functions. It is because of the inferred primacy of the role of the limbic system in emotional behavior that in psychiatric parlance I have used the term "visceral" in its original Elizabethan meaning and applied it in quotation marks to the brain included in this system.[45]

Having given these introductory remarks, we turn now to dwell on the question of hippocampal function. This topic merits special consideration for the following reasons. In the first place, the hippocampus in association with the other structures making up the hippocampal formation is strategically related to the heart of the limbic system. An effort to extricate ourselves from the sea of ignorance that surrounds these structures would therefore

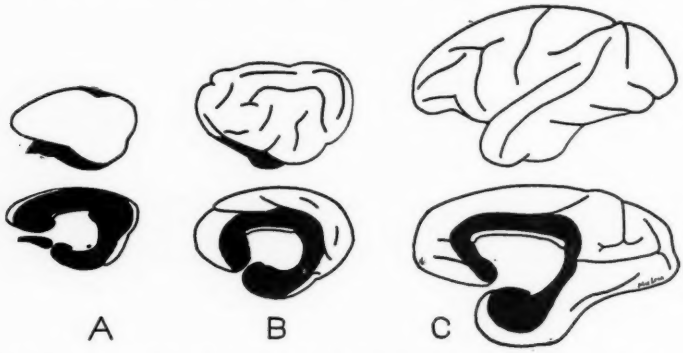

FIG. 1. Lateral and medial surfaces of brains of rabbit (A), cat (B), and monkey (C), drawn roughly to scale. As shown by Broca,[6] the drawings illustrate that the limbic lobe, represented in black, forms a common denominator in the brains of all mammals.

seem to be a prerequisite for any significant advance in our knowledge of the limbic system. But what makes the foregoing question of immediate interest to the neurosurgeon is the growing realization that morbid processes in these structures are basically concerned in the pathogenesis of psychomotor epilepsy.*[15,28,29,46,49,64]

In a psychophysiological review of the limbic system in 1949,[45] I presented the diagram in Fig. 2 to illustrate the possible convergence of the intero- and exteroceptive systems in the hippocampal gyrus and the hippocampus. It was inspired by discussions with Dr. Papez and was based on a number of fragmentary anatomical and physiological observations. From the cytoarchitectural studies of Lorente de Nó[42] one finds there is an overlapping of the incoming systems into the hippocampal gyrus. In the case of the diagram, this would allow an overlap of impressions coming from the mouth, nose, viscera, sex organs, eye, ear, and body wall. In another diagram it was

* The peculiar rake-like, end-arterial blood supply to the hippocampus makes this structure vulnerable to a number of affections. The work of Scharrer[65] and Nilges[54] should be consulted for further details. This gains further significance in the light of the low seizure threshold of the hippocampus.[39,63]

emphasized that this part of the brain, in contrast to the neopallium, has strong connections with the hypothalamus.

Generally speaking, the limbic cortex can be distinguished from the surrounding neopallium by (i) the absence or poorer development of the supragranular layers, (ii) the ending of the afferent plexus in the superficial layers, and (iii) the relative paucity of cells of short axon.[42,43,61] These phylogenetically primitive characteristics are nowhere better demonstrated than in respective parts of the hippocampal formation. The foregoing considerations, in conjunction with the emotional changes presumably associated with

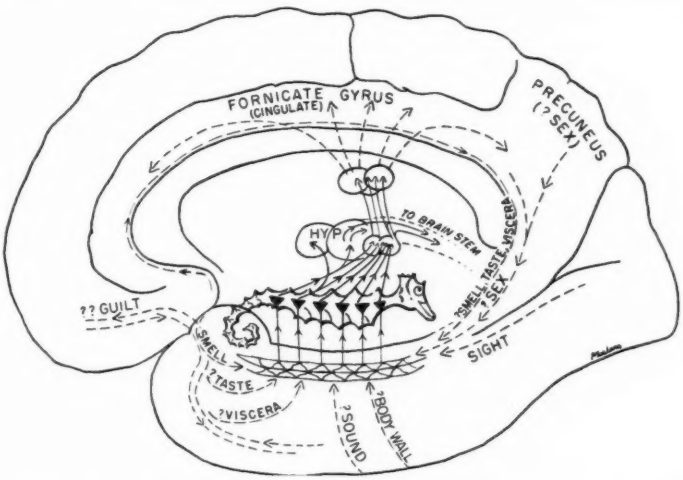

FIG. 2. This figure was presented in 1949[45] to illustrate the possible convergence and overlap of intero- and exteroceptive systems in the hippocampal formation. See text for recent developments.

disease or experimental manipulation of this part of the brain, were the basis for the suggestion that the structures making up the hippocampal formation derived information largely in terms of "feeling."

No experiment is so compelling as the one contrived by Nature to support the thesis that the mediobasal cortex of the frontotemporal region allows a confluence of the various bodily senses and imparts to them the quality of feeling. Although foreseen in the observations of several workers in the last century, of whom we should mention particularly Herpin and Sommer on the Continent, Hughlings Jackson in England, and Allan McLane Hamilton in this country, it remained for present-day electroencephalography to establish that discharges in this part of the brain may be associated with a wide variety of auras involving all the bodily senses and a great number of feeling and emotional states. Among the more purely sensory auras are crude olfactory sensations; alimentary symptoms including taste, thirst, hunger, nausea; cardiorespiratory manifestations when there may be such sensations as choking or a racing heart; somatic sensations ranging all

the way from pains in the head to paresthesias in the buttocks; crude auditory or visual experiences in which sounds seem unusually loud or objects appear inappropriately small or large. There may even be symptoms referable to the genitals. The feeling states with emotional coloring are also great in number: feeling of fear or terror, "nervous, shivery" feelings, feeling of familiarity, feeling of strangeness, feeling of wanting to be alone, feeling of wanting somebody near, feeling of sadness and wanting to cry, etc.

With the exception of the olfactory auras, it has not been at all clear what anatomicophysiological substratum accounts for the other sensory phenomena that have been enumerated. It is only recently that physiological studies have borne out the claims of comparative neurology and demonstrated that senses other than olfaction are afferently related to this region.

RESPONSES OBTAINED IN HIPPOCAMPAL FORMATION BY STIMULATION OF SENSORY SYSTEMS

In regard to the hippocampal formation (in which we include hippocampal and dentate gyri, hippocampus and amygdala[45]) the responses obtained by various types of sensory stimulations fall into a number of categories. Dell and Olson[13,14] have evoked spike potentials in the pyriform cortex and amygdala by stimulation of the vagus nerve. Several workers, including Gerard, Marshall and Saul,[24] Robinson and Lennox,[62] Dell and coworkers,[12] Liberson and Cadilhac,[41] have variously elicited potentials of the same order in the amygdala, hippocampal gyrus, and hippocampus by auditory, visual, and somatic stimulation. It should be emphasized, however, that there are a number of discrepancies in the findings of these investigators, and more data are needed before the contradictions can be reconciled.

In our studies of the bioelectrical properties of the olfactory system, Horwitz, Robinson and I[51] were struck on finding that either gustatory or noxious stimulation resulted in the appearance of rhythmically recurring potentials in the pyriform area of the rabbit somewhat like those induced by olfactory stimulation and first described by Adrian.[1] We have observed these olfactory-like responses only in moderately deep stages of nembutal anesthesia. The records in Fig. 3 illustrate the character of the olfactory-like potentials elicited by gustatory or noxious stimulation. In this instance, the olfactory-like responses were obtained by a hard pinch of the rabbit's tail. The top record shows a typical response to olfactory stimulation for comparison. The response in the next record resulted from a six-second pinch of the rabbit's tail. In the last record, one observes that just a single short pinch of the tail results in almost as great and as long a response, calling to mind the nature of one's subjective sensations on receiving a short hard pinch.

In the anesthetized animal, we have not observed such olfactory-like responses following short-lasting visual or auditory stimulation. In moderately deep anesthesia, one finds, however, a curious succession of potential

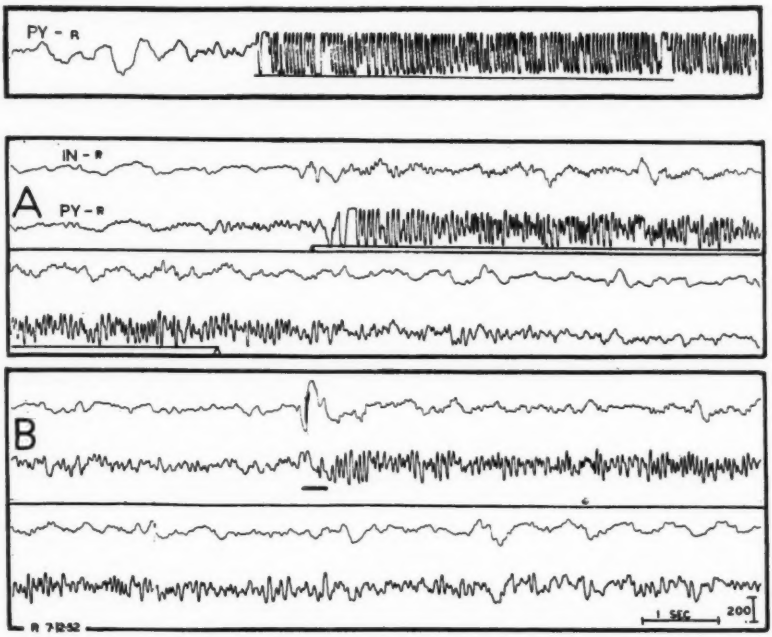

FIG. 3. These records from a previous publication[51] illustrate the character of olfactory-like responses that appear in the pyriform area following gustatory or noxious stimulation in the anesthetized rabbit (nembutal). Top record shows for comparison a response to olfactory stimulation. In A, the rabbit received a 6-second pinch of the tail. In B, it is seen that a single hard pinch results in almost as great and as long a response. Lines under recordings indicate approximate duration of the stimulus. PY, IN, R, refer to pyriform, insular, and reference leads, respectively.

changes in the pyriform area following a loud hand clap. The consistency of these responses is illustrated in Fig. 4, which shows excerpts of a bipolar recording from the pyriform area during a series of 14 hand claps. In the top line, an example of the concurrent response in the primary auditory projection area is given for comparison. In all the records from the pyriform area, one sees a small early deflection occurring in association with the primary response from the temporal cortex. This is followed by a wave-form that is comparable in latency to the so-called secondary response. Finally, over half a second later there appears quite consistently a third distinctive change of potential.

Elsewhere, we have elaborated on the implications of the prolonged rhythmic responses elicited in the pyriform area by olfactory, gustatory, and painful stimulation.[51] It is to be noted particularly that all three of the involved senses accent the quality and intensity of a stimulus rather than its spatial relationships. It is interesting to reflect, too, that emotion which is frequently experienced in conjunction with discharges in this part of the

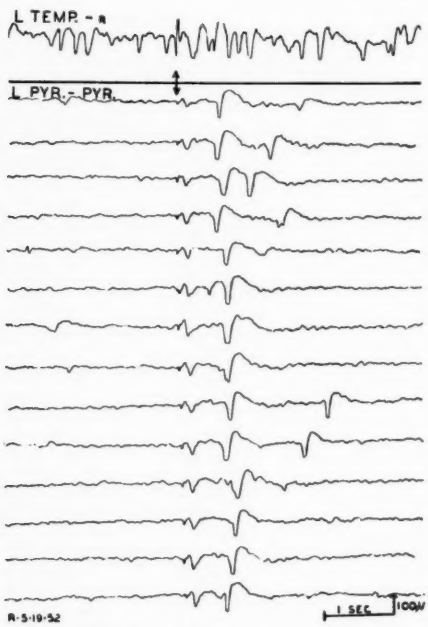

FIG. 4. Bottom 14 lines are excerpts of a bipolar recording from the pyriform cortex to show the consistency of responses obtained following a series of hand claps (arrow). Rabbit had just received a supplementary dose of nembutal intravenously. Top line shows a sample of the concurrent responses recorded from the temporal cortex.

brain is like the foregoing senses insofar as it is registered in terms of quality and intensity.

It has subsequently been found that rhythmic activity (usually of a much slower frequency than that seen in the pyriform area) can be recorded from the hippocampus following several forms of sensory stimulation. Over 14 years ago, Jung and Kornmüller[30] reported that synchronized activity around 6 per second occurred in the hippocampus of the waking rabbit when the animal received a hard pinch. We observed synchronized activity in the hippocampus of both rabbit and cat following natural olfactory stimulation, but only rarely after gustatory stimulation.[51] These findings have been greatly augmented by the studies of Green and Arduini.[25] At the last meeting of the International Physiological Congress, these workers reported that "physiological stimulation of olfactory, visual, auditory and somatic receptors" in rabbit, cat, and monkey may evoke "a train of high amplitude, slow waves at 3–6 per second" in the hippocampus.

Liberson and Akert[39] have reported that synchronized activity around 6 per second may be recorded from the hippocampus of the guinea pig when the animal is alerted to the presence of the experimenter. At the same time, there is desynchronization of the neocortical activity. Electrical stimulation of the reticular activating system, according to Green and Arduini,[25] results in comparable findings. Furthermore, they state that trains of waves are initiated in the hippocampus by "arousing stimuli" that are too weak to affect the neocortex.

Thus, in addition to cytoarchitectural and chemical* differences, one finds that the bioelectrical findings described in this section provide further evidence for inferring that the mechanism of communication in the phylo-

* The cholinesterase and cholinacetylase content of the uncinate region, for example, is considerably higher than that found in the neocortex.[8,16,44]

genetically primitive cortex is markedly unlike that in the neopallium. As yet one can only speculate about what these differences mean in terms of feeling (emotion) and intellect. But it is apparent at least that the foregoing studies give a physiological clue to the diversity of sensory auras associated with epileptogenic foci in this part of the brain.

ABLATION STUDIES

Before considering the motor phenomena associated with stimulation of the hippocampal formation, a few words may be said about the effect of excisions that interrupt the normal flow of impulses between its afferent and efferent pathways. To date, experiments aimed at ablation of the hippocampus alone,[2,5] or severing its projections by way of the fornix,[20] have revealed disappointingly little in the way of behavioral changes. On the other hand, Thomson and Walker,[69] Pribram and Bagshaw,[59] and Shreiner and Kling,[66] have variously observed manifestations of the Klüver-Bucy syndrome[33] when lesions are restricted to parts of the rostral hippocampal formation. Altogether, the changes observed in these studies may be characterized and enumerated as follows: 1) an apparent taming of wild animals, 2) a tendency of the animal to examine everything with the mouth, 3) a failure to persist in avoiding noxious stimuli, 4) an alteration in dietary habits, and 5) bizarre sexual behavior. Whether ablation of the rostral hippocampus is essential to obtaining these manifestations is not clear. It is interesting that excision of cortex which yields the prolonged rhythmic responses upon olfactory, gustatory and noxious stimulation (see preceding section), appears to be correlated with the animal's change in dietary habits and his tendency to expose himself again and again to painful stimuli.

STIMULATION STUDIES

There is a large and growing number of communications in which the reported results of stimulation of various parts of the rostral hippocampal formation indicate that this part of the brain has a profound influence on the autonomic regulation of respiratory, cardiovascular, and alimentary functions.* The studies employing stimulation in the intact, unrestrained, and waking animal, have elucidated to a considerable extent the part this region plays in general behavior.[22,23,31,50] Since much of this work has already been reviewed,[19,21,31,47] I shall only pause to say that an evaluation of all the results would seem to indicate that this frontotemporal portion of the limbic system is concerned with the organization of the oral activities of the animal as they pertain to eating, and to the vocalization, attack and defense involved in obtaining food.

Stimulation studies, however, have thus far been little more successful than ablation methods in elucidating the functions of the bulk of the hippocampal formation lying posterior to the portion just considered. The greater

* The reader is referred to Kaada[31] and Gastaut[21] for excellent reviews. A number of recent Japanese publications on this subject are cited in the references.[34,35,68]

part of the body of the hippocampus is included in this region and appear to be the main channel for efferent impulses.* In a continuation of our electrical and chemical stimulation studies on the limbic system, I have focused attention during the last year particularly on the posterior part of the hippocampus.[48] A technique was used that allows one to stimulate electrically or chemically the same point, and at the same time to record the bioelectrical changes while the animal is free to move about as he chooses. Cholinergic drugs were used as the exciting agents.†

Save perhaps for some enhancement of grooming and pleasure reactions, I have found repeatedly that excitation of the posterior hippocampus of the cat by cholinergic drugs results in little spontaneous change of behavior that can be ascribed to altered bioelectrical activity in this structure. It may be significant, however, that two mean and fearful animals I was obliged to use owing to a shortage of cats, never manifested spontaneous pleasure reactions until the posterior hippocampus was chemically activated. For the first time they became actively receptive to petting.

There are also few observable changes upon electrical stimulation. The responses most commonly seen are some contraversive movements of the head and ipsilateral closure of the eye. The animal, if purring, continues to do so throughout the stimulation. In some instances, possibly because the electrodes impinge on fimbrial fibers from the rostral hippocampus, one can elicit cringing, defensive attitudes in which there is a retraction of the ipsilateral ear, a wrinkling of the face, and a pulling of the head away from the stimulated side. Rarely, one hears meowing or a hiss.

More dramatic changes are seen during afterdischarges which follow stimulations of greater strength. Any turning movements that were present during the initial stimulation appear to reverse themselves with the onset of the afterdischarge, and the pupils may suddenly dilate. Purring, if previously present, may cease and be replaced by occasional meows or yowls. Concurrently, the animal assumes attitudes that strike one at first as being wrapt attention or fearful alerting for the unexpected. Further examination indicates, however, that the animal is poorly in contact with his environment. Although the pupils react to light, the animal will not avoid the light, nor will he cringe when one pretends to strike the face. If one forcefully blows smoke at him, he will withdraw a little, but will not avoid the smoke. A burning cigarette may be brought up to his nose with no response, but if

* There is some indication that the anterior and posterior portions of the hippocampus may differ significantly in their projections upon the septum and hypothalamus.[17,58,67]

† Acetylcholine (in conjunction with physostigmine) and mecholyl were the drugs most commonly used. Carbachol was employed on a few occasions. The use of solutions was abandoned in these experiments because of the ease with which they leak back along the needle into the ventricle when the posterior hippocampus is injected. It was found in the cat that such a leaking back of small amounts of eserine in combination with acetylcholine or mecholyl was followed roughly five minutes later by growling, contralateral turning, ferocious behavior, pupillary dilatation, piloerection, and sometimes shivering or panting. These manifestations commonly lasted an hour or more. The results of the stimulation and electroencephalographic studies to be summarized in this and the following section were based on observations on 27 cats, 4 squirrel monkeys, and 2 macaques.

there is momentary contact with the lighted end, the animal may lunge about wildly. The emotional changes that one may induce during an afterdischarge are most interesting:* If one takes an animal which prior to stimulation simply meows when the tail is pinched, one finds that the same noxious stimulus will cause it to hiss, spit, and strike out during the afterdischarge. A prolonged or repeated noxious stimulus may lead to states of wild excitement, accompanied by spitting and hissing. I have held on to the tip of the tail of such an animal and observed a state of rage in which he would not properly orient his attack, but rather would viciously bite at the stump of his tail. It is striking that these excited states may suddenly terminate in rather prolonged catatonic-like stances. A meow or series of meows usually signals the end of the afterdischarge.

Addendum. Since this paper was submitted for publication, it has been found that the hippocampal injection of carbachol in somewhat larger quantities than previously employed results in spontaneous or induced behavioral changes comparable to those seen during afterdischarges produced by electrical stimulation. One has the opportunity to observe these changes for an hour or more during the continuous high voltage seizure activity. When the intense seizure activity begins to abate, the animal manifests enhanced pleasure reactions.

PROPAGATION OF HIPPOCAMPAL AFTERDISCHARGES

We shall postpone a discussion of some of the foregoing findings until we have considered the propagation of afterdischarges that are initiated in the limbic system. Kaada[31] has made the highly significant observation that such seizure activity has the tendency to spread in and be largely confined to the limbic system. The shading in Fig. 5, which is based on the comparative neuronographic studies of Pribram and myself,[52,60] gives one an estimation of the peripheral extent of limbic connections into the surrounding neopallium. In regard to the hippocampus,† Kaada states that "afterdischarges [initiated there] . . . readily spread into the entire limbic . . . cortex of both sides, and further to the cortex just lateral to the rhinal fissure. . . . " His observations were made in anesthetized animals. My findings in the drug-immobilized animal (cat, squirrel monkey, macaque) are in agreement with this, and support Kaada's statement that it is only with stronger stimuli that one finds a *further* spread of the discharge into the cortex of the lateral convexity. *It is to be emphasized that there may be a propagation of hippocampal discharges without a discernible alteration of neocortical activity.*

The local application of cholinergic drugs provides another means of producing seizure activity in the hippocampus. When carbachol is the agent,

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* Cf. Andy and Akert.[4]

† Several papers dealing with hippocampal seizures and the propagation of hippocampal discharges have been presented in the last year, abstracts of which may be found in the cited references.[3,4,11,26,38,40,48]

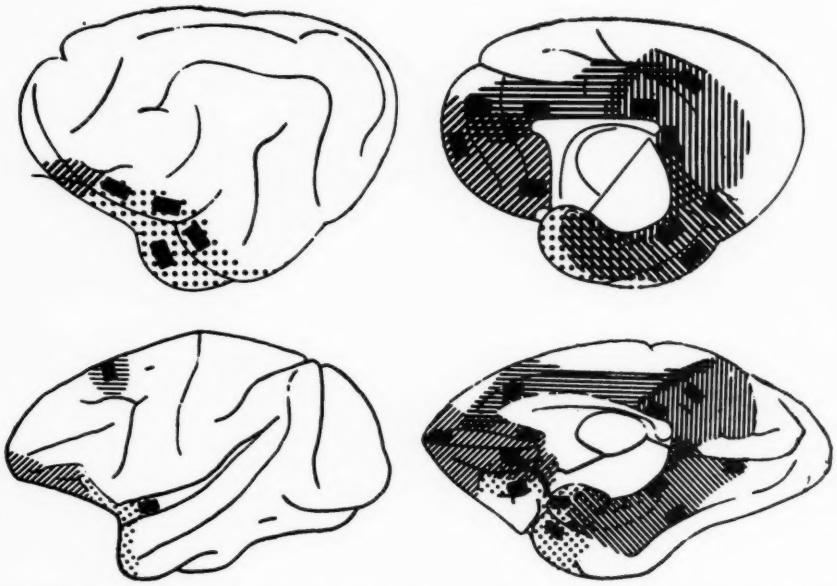

FIG. 5. Shading on the lateral and medial surfaces of cat's and monkey's brain, respectively, indicates peripheral extent of limbic connections into the neocortex as demonstrated by strychnine neuronography. The illustration is adapted from ones previously published,[52,60] and for the present purposes the various shadings and rectangles on the limbic and extralimbic cortex may be ignored.

the seizure activity may last for hours. Fig. 6 shows such activity in the hippocampus of a macaque, and illustrates it may be present without a discernible seizure activity in the neocortex. As evident from Fig. 7, the configurations of the chemically induced seizures may be quite similar to those of afterdischarges that are produced electrically. In this instance, where carbachol was applied to the hippocampus of a cat, there appears to be some spread of the discharge into the caudate.

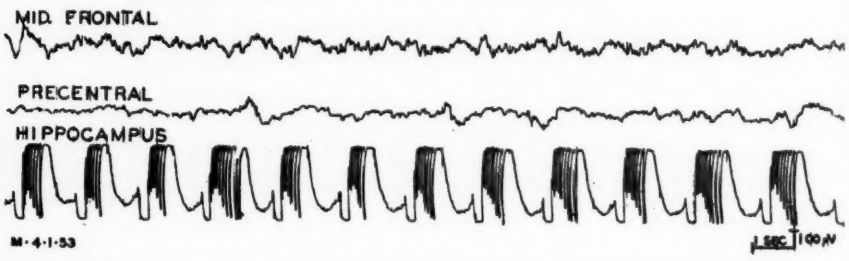

FIG. 6. Seizure activity in hippocampus of curarized macaque, elicited by local application of carbachol. Bipolar recordings from middle frontal and precentral gyri illustrate absence of discernible concurrent seizure activity in the neocortex.

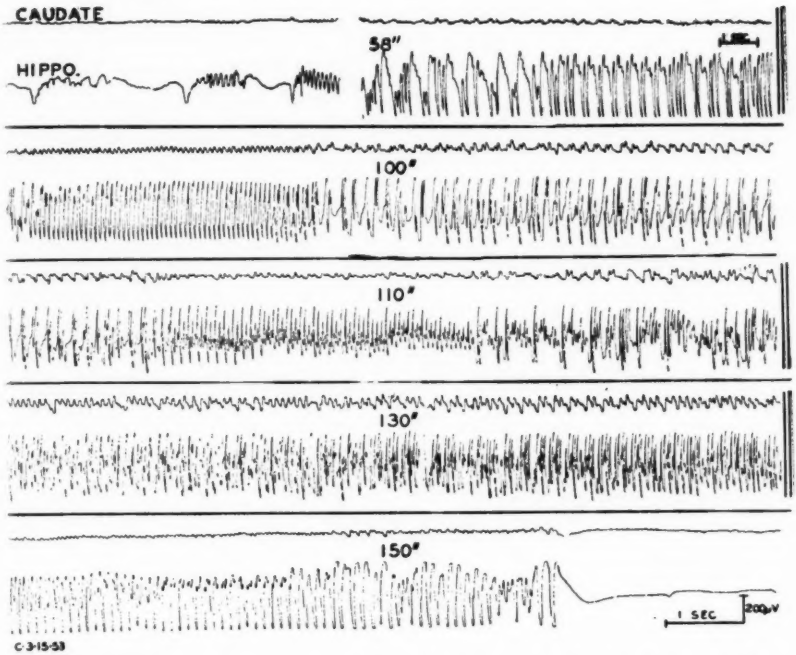

FIG. 7. Seizure activity in hippocampus of curarized cat, induced by local application of carbachol. Configurations of the potential changes have similarities to those of afterdischarges produced by electrical stimulation. In this instance there appears to be some spread of the discharge to the caudate. Bipolar recordings.

DISCUSSION OF STIMULATION AND ELECTROENCEPHALOGRAPHIC STUDIES

From the mapping of afterdischarges, one gets the impression that there exists a potential "schizophysiology" of the neopallium and limbic cortex. This is fraught with significant implications that bear on both the behavioral changes accompanying induced hippocampal seizures in the animal and on certain epileptic and psychopathological conditions in man.

It will be a matter of great interest to investigate the mechanism by which a noxious stimulus is able to precipitate a state of wild excitement in an animal during a hippocampal seizure. The sudden explosion of fury calls to mind the behavior of some patients with psychomotor epilepsy when an effort is made to impede their course of action during a seizure. On the other hand, the cat's equally sudden shift from wild excitement to frozen immobility is reminiscent of the behavioral fluctuations of patients with catatonic schizophrenia. We have not yet mapped the spread of hippocampal afterdischarge in an animal thrashing about following the applica-

tion of a noxious stimulus. One does not know, therefore, whether or not it is primarily dysfunction within the limbic and closely related systems that allows the development of the phenomena in question. The latter give the impression of corresponding to alternating states of massive release and inhibition, respectively.

It is possible that seizure activity largely confined to the limbic system may have a bearing on some of the epileptic behavior, as well as the post-epileptic amnesia, of patients with psychomotor epilepsy. For illustrative purposes, it will be sufficient to cite a single case and one that is generally familiar. This is Hughlings Jackson's famous Case Z, which describes the seizures of a young doctor who at postmortem was found to have a small area of softening in the region of the left uncinate gyrus.[27] During a fit, he

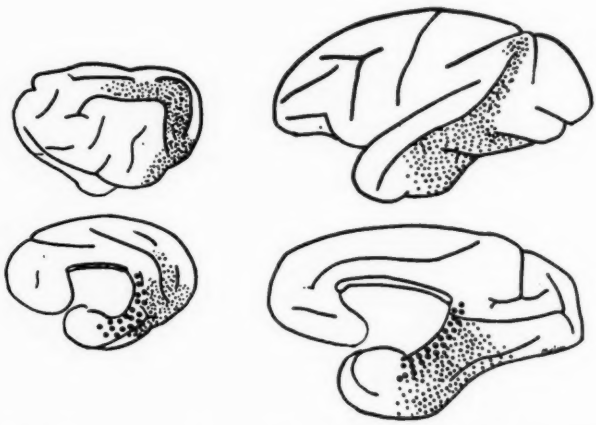

FIG. 8. Strychnine neuronographic studies[52,57,60] indicate that the posterior hippocampal formation is but one synapse removed from a large expanse of parieto-occipito-temporal cortex to which Penfield[56] ascribes the functions of memory and dreaming. These diagrams homologize these interrelated limbic (large stipple) and neocortical (small stipple) regions in the cat and monkey.

was able to stoop over and pick up a pin or to continue the physical examination of a patient and to write a reasonable diagnosis, all with a subsequent amnesia for what had happened. It strains the imagination to conceive how such acts requiring both manual and intellectual skill could have been performed in the absence of a functioning neocortex. That seizure activity may take place in the limbic system without appreciable alteration of the neocortical activity (cf. above) possibly gives some insight into the mechanisms of such epileptic behavior.

But why the subsequent amnesia? In discussing the symbolic process, Kubie[36,37] has emphasized that memory is dependent on the interplay of intrabodily and externally derived experience. He refers to the former as the gut component of memory. The limbic cortex is strongly related to the

hypothalamus, which, to use Le Gros Clark's phraseology,[9] is concerned "with all sorts of visceral and metabolic processes" that in their totality enable the organism "to appreciate itself as a unified being." Furthermore, neuronographic studies[52,57,60] indicate that the posterior part of the hippocampal formation is but one synapse removed from a large expanse of parieto-occipito-temporal cortex to which Penfield[56] ascribes the functions of memory and dreaming. Fig. 8 homologizes these areas of associated cortex in the cat and monkey. Kubie,[37] as the result of some collaborative studies with Penfield, has suggested that in the transitional region of the limbic and temporal cortex there may be an amalgamation of the "gut" component and the verbal component of memory, the place where the "I" and the "non-I" meet. From the foregoing considerations, might one infer that the experiences during a "psychomotor" attack are lost to recollection because the limbic discharges interfere particularly with the recording of internally derived impressions?

SUMMARIZING COMMENT

The foregoing sections have dealt with a number of evoked potential, ablation, stimulation, and electroencephalographic studies that have been undertaken in the analysis of the functions of the hippocampal formation in the animal. In each instance some of the relevance of the data to clinical problems was discussed. From the evoked potential studies, one obtains a physiological clue to the diversity of sensory auras associated with epileptogenic foci in this part of the brain. The stimulation and electroencephalographic studies, on the other hand, possibly give some insight into the nature of the functional derangement associated with some of the epileptic behavior and the post-epileptic amnesia of patients with "psychomotor" seizures.

In conclusion, it might be noted that animal experimentation can contribute next to nothing about the "subjective" functions of the hippocampal formation. To corrupt a statement by Wiener,[70] psyche is information, not matter or energy. The animal cannot communicate how he feels. Here is the rub for the physiologist. Realizing that Aladdin's lamp is not for him, he obviously looks, as he has long been accustomed, to the neurosurgeon!

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THE VISCERAL BRAIN OF MAN*

J. LAWRENCE POOL, M.D.

Departments of Neurological Surgery, Neurological Institute, Presbyterian Hospital of New York, and Columbia University, New York, N. Y.

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GASTRO-INTESTINAL, vasomotor, and other visceral disturbances secondary to focal brain lesions are phenomena of obvious importance not only to the neurosurgeon, neurologist and psychiatrist but also to the general surgeon, genito-urinary specialist, pediatrician and obstetrician.

Birth trauma, for example, may produce injuries of the hippocampal gyri[23] leading subsequently to visceral disturbances associated with psychomotor attacks.[8,29,30,72] Paroxysmal abdominal pain and intussusception may be manifestations of epilepsy in children[37] and adults. Laparotomies have occasionally been done for gastro-intestinal symptoms, cystoscopic studies for difficulties in voiding, and electric shock treatments for viscero-emotional disturbances although the initial visceral symptoms in all these cases might have led to an earlier diagnosis of an organic cerebral lesion.

With regard to the frequent association of visceral and emotional disturbances, it is of interest to note that this important phenomenon has long been recognized, as indicated by the Lamentations of Jeremiah (Chapter I) in the old Testament: " . . . mine eye runneth down with water . . . I am in distress: my bowels are troubled . . . my sighs are many, and my heart is faint."

The viscera, strictly speaking, include only the soft hollow organs of the body such as the heart, blood vessels, gut, urinary bladder and lacrimal sac. For the purposes of this discussion, however, mention will also be made of respiratory phenomena. Both visceral and respiratory disturbances will therefore be considered with regard to their representation in the cerebral cortex as indicated by focal brain lesions or electrical stimulation. Visceral phenomena secondary to massive intracranial lesions or generalized increased intracranial pressure will not be considered, having no localizing value.

While it has long been known that visceral symptoms such as pallor, salivation and epigastric distress may herald or accompany an epileptic seizure, these symptoms cannot be regarded as having any localizing value unless a focal brain lesion is proved to be their cause. With increasing frequency in recent years, however, it has been shown that specific visceral phenomena of this and other kinds are often caused by focal lesions involving certain parts of the frontal or temporal cortex or the insula (island of Reil). Reasonably accurate localization of cerebral pathology in such cases has

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been made by pneumoencephalography or ventriculography, surface and depth electroencephalography, angiography and intracranial surgery for verification by inspection, electrical studies and biopsy.

In the last analysis, however, methods of localizing function in the human brain are relatively crude, for the precise extent and effects of a brain tumor, scar or cortical ablation upon adjacent brain tissue are difficult to define. Likewise the exact extent of spontaneous or artificially induced abnormalities in electrical activity may be equally difficult to determine. Nonetheless, when brain lesions or electrical excitation of specific parts of the brain result consistently in similar effects, there is ground for accepting a localization of function. This is particularly true of brain tumors that give rise to specific visceral symptomatology long before any other symptoms occur, especially when these visceral disturbances disappear following removal of the lesion.

Electrical stimulation of the brain is unquestionably a more nearly accurate means of localizing function in the sense that it is usually possible to elicit constant and consistent effects from relatively discrete points, whereas no effect or a different effect may be produced by stimulation only 2 mm. away. The fact that electrical stimulation may not yield an expected visceral response on excitation of a given cortical area may be caused by such influences as medication, anesthetic agents, metabolic or pathologic changes, existing background activity of the brain or viscera, or individual anatomical variations.

Despite these factors of inconstancy and uncertainty it is apparent that the effects of various lesions as well as electrical stimulation of the human brain indicate more or less discrete localization of visceral functions in the cerebral cortex.

Before assembling these data in diagrammatic form (Figs. 1–5) a few illustrative case summaries of brain lesions, including cortical ablations, will be presented with emphasis on visceral symptomatology. Observations on the effects of electrical stimulation and recording will then be described.

Additional data reported by others have been included in Figs. 1, 2, 3 and 5. Penfield, *et al.*,[71,73,74] for example, have provided ample evidence that neoplastic or atrophic lesions of anteromedial temporal cortex and the insula may give rise to episodic vasomotor disturbances, such as pallor or tachycardia, and distressing epigastric sensations. Epigastric aura may also be secondary to "frontal intermediate" lesions.[75] Others[20,65] have confirmed the temporal and insular source of epigastric sensations.

Bucy,[14] moreover, has described alteration of the peripheral circulation in the contralateral extremities following premotor cortical ablation, and also mentioned sudomotor changes secondary to lesions in this region. Scoville has reported transitory alterations in pulse rate on isolating the anterior cingulate gyri bilaterally,[88,89] and vomiting in several cases after uncotomy.[90]

CASE SUMMARIES

I. BRAIN LESIONS

1. *Anterior Temporal Cortex Gliosis: Gastro-intestinal symptoms.*

Case 1. Mc.C., 28-year-old machine inspector. His employment was threatened because of weekly attacks of sudden partial loss of contact with environment lasting a few seconds, always preceded by a sense of profound gastric distress and a feeling that someone was talking behind him.

Past History. Nine months gestation; 4 hours labor; instrument delivery without known abnormal effects. Head injury at 15 months with unconsciousness for 24 hours. At 4 years of age he began to suffer sudden attacks of ashy pallor, abdominal pain and nausea lasting a few seconds, and occasionally vomited. At 7 years: occasionally unconscious for 2 or 3 minutes and "stiff" in face and extremities after aura described above. He might then be drowsy for 1 or 2 hours. He also had unexplained "mucous colitis" for 3 months.

At age 29 (May 1952) the EEG showed a right anterior temporal focus on a sleep record. Previous waking EEG studies showed no focal signs but some abnormal bilateral medium voltage slow wave activity. A thorough 12-year trial of various anticonvulsant medications having failed to arrest attacks, surgery was elected.

Operation, May 1952. Right temporal craniotomy. Pentothal sodium anesthesia. The cerebral cortex appeared grossly normal but ECG indicated abnormal activity confined to the anterior thirds of the middle and inferior temporal gyri. This cortex was accordingly excised down to and including the uncus.

Pathology. Microscopic study revealed moderate gliosis, no tumor, and numerous monocytic phagocytes filled with yellow pigment clustered about the blood vessels, compatible with a long-standing, post-traumatic atrophic process.

Postoperative Course to April 1953. No further attacks, epigastric aura or "colitis." No personality changes. The patient is extremely pleased with operative results, and is fully employed at his former job.

2. *Bilateral Subfrontal Tumor: Constipation* 6 months.

Case 2. J.S., 49-year-old executive. Initial symptom was marked constipation for 4 months, for the first time in his adult life, without change in diet or fluid intake. This was followed by visual impairment for 2 months, and later by papilledema and headaches without focal signs. He had previously had unusually regular bowel habits. Constipation continued for the whole 6 months preceding surgery.

Operation. Ventriculogram and right frontal craniotomy revealed a low bilateral subfrontal invasive tumor. It was soft and necrotic and not accompanied by marked increase of intracranial pressure. A generous bilateral subtotal removal of tumor (angionecrotic glioblastoma) was done.

Postoperative Course. X-ray therapy was given. Vision improved and no further constipation occurred. A year after operation the patient was promoted to a more important executive post. No personality or mental changes have been observed by friends or family during the 3½ years since operation.

3. *Superior Frontal Convexity Tumor: Urinary retention* after progressive difficulty in voiding of 6 years' duration.

Case 3. J.W., a 50-year-old executive, had suffered progressive difficulty in void-

ing for 6 years. For more than a year prior to admission he had to sit on the toilet for 20 to 30 minutes in order to strain hard enough to empty his bladder. Repeated cystometric and cystoscopic studies by a number of G.U. specialists failed to disclose the cause of his difficulty. He finally became depressed, for which electroshock therapy was administered. Following this, signs of increased intracranial pressure developed without definite localizing signs.

Operation. Ventriculogram and right frontal craniotomy disclosed a convexity meningioma, 3.5 cm. in diameter, close to the falx cerebri. The posterior margin of the tumor lay beneath the coronal suture.

Course. Following total removal of the mass in 1948 there has been no further difficulty in voiding.

4. *Frontoparietal Parasagittal Tumor: Urinary frequency* and abdominal pressure sensations for 2 weeks.

Case 4. M.R., a 50-year-old right-handed male, was admitted on Oct. 10, 1949. Three months previously he had experienced fleeting weakness and a hot sensation in the left leg. During the following 2 weeks, when he had no further symptoms in the leg, he noted marked frequency of urination, nocturia, and a sense of pressure in the lower abdomen even though the bladder was empty. As these symptoms disappeared he began to suffer focal seizures starting in the left big toe, and later the left leg became weak.

Operation. On Oct. 28, 1949 a glioblastoma multiforme was found in the right sensorimotor cortex and paracentral lobule.

Course. There were no personality changes.

5. *Deep Temporal Lobe Pathology (type unknown): Colon spasm* with partial obstruction of colon; cecostomy and laparotomy.

Case 5. D.B., a 45-year-old male, was admitted to a general surgical service because of cramping abdominal pain, abdominal distension, vomiting and signs of partial intestinal obstruction. Barium enema revealed marked spasm and partial obstruction of the sigmoid colon, for which cecostomy was done. Three days later exploratory laparotomy disclosed no tumor or inflammatory process but did reveal marked spasm of the entire colon. Two days later a generalized convulsion occurred.

A neurological consultant was called who found a right homonymous hemianopsia, dysphasia, and right-sided hyperreflexia, but no papilledema. EEG showed a left temporal focus of abnormal activity. Angiography suggested the presence of a low parietal or temporal lobe mass.

Operation. Craniotomy failed to disclose any evidence of gross pathology or increased pressure.

Course. Despite supportive measures the patient became progressively drowsy and died 18 days later.

Autopsy disclosed no evidence of tumor, vascular pathology or inflammatory process in the brain, brain stem, gastro-intestinal tract or elsewhere. Cultures of the cerebrospinal fluid for torula and other organisms were negative.

Comment. While the cause of death in Case 5 thus far remains obscure (additional sections of the brain are in preparation), the visual field defect, other neurological findings and EEG indicated a deep temporal lobe dis-

turbance on the left. Careful consideration of this case strongly suggests a central origin for the spasm of the colon, although proof as yet is lacking.

6. *Tumor of Insula and Adjacent Temporofrontal Cortex: Alternating diarrhea and constipation* 3 months.

Case 6. K.W., a 47-year-old male, suffered alternating diarrhea and constipation for 3 months prior to the onset of headaches, nausea and vomiting. The latter symptoms, which began 3 weeks before admission, were associated with personality changes in the direction of uncooperative behavior. Clinical studies led to a diagnosis of right temporal lobe tumor.

Operation confirmed the presence of tumor. An internal decompression was done.

Course. There was only temporary relief of pressure symptoms and the patient expired 10 days after operation.

Autopsy showed that a glioblastoma multiforme had invaded the insula and adjacent temporal and subfrontal cortex.

II. CORTICAL ABLATIONS

1. *Frontal Lobe: Fecal incontinence upon unilateral ablation of Area 6* (local anesthesia).

Case 7. D.S., a 32-year-old right-handed woman was operated upon under local novocain anesthesia at a city hospital in 1941, at a time when excision of Area 6 of Brodmann[12] was often done for the relief of Parkinsonian rigidity and tremor. She suffered from marked rigidity and tremor, mostly of the left extremities, as the result of encephalitis.

Operation. Right frontal craniotomy revealed a somewhat atrophic-looking brain. The motor cortex for arm, hand and leg was outlined by electrical stimulation, and it should be emphasized that at no time during the entire operative procedure did the patient lose consciousness or contact with the environment. Indeed, she was unusually alert and cooperative throughout the operation.

The central and precentral fissures having been identified, a block of cortex approximately 2.5 cm. in the anteroposterior plane, 3.0 cm. in the dorsoventral plane, and 2.0 cm. in depth was outlined for resection. Silver clips rather than the electrocautery were used for hemostasis. The proposed margins of the excision began 3 mm. anterior to the precentral fissure, and extended almost to the falx. With a No. 11 scalpel the anterior margin of the cortical excision was first incised, and then the ventral margin. As the posterior margin was completed the patient suddenly exclaimed: "Oh, doctor, my bowels are moving, my bowels are moving and I'm trying to stop them but I can't. I'm terribly sorry—I apologize, but I just can't help it." A large stool was evacuated at this juncture.

Course. Following operation she was never incontinent of either urine or feces. The left extremities were temporarily weak, though never paralyzed. Improvement in rigidity was only transitory.

2. *Bilateral Anteromedial Temporal Lobectomy: Abnormal oral or "feeding" behavior.*

Case 8. A middle-aged chronically psychotic female was admitted to a psychi-

atric hospital for alleviation of extremely assaultive, unpredictable behavior that made her a taxing problem in ward management. She was childishly simple in general attitude and responses. Psychotherapy and electric shock treatment had been tried without success. The diagnosis was hebephrenic schizophrenia.

Psychosurgery was advocated by the psychiatric staff as a last resort. It was felt that even a radical prefrontal lobotomy would not alleviate her assaultive behavior except at the cost of creating an incontinent and thus equally unmanageable patient. Bilateral anteromedial temporal lobectomy was therefore suggested on the basis of laboratory data showing that such an operation in primates converted ferocious animals into tame and tractable beasts, provided the uncus was bilaterally removed.[4] The operation might also distort feeding habits to the extent that almost any available object might be seized, placed in the mouth, and chewed or swallowed, regard-

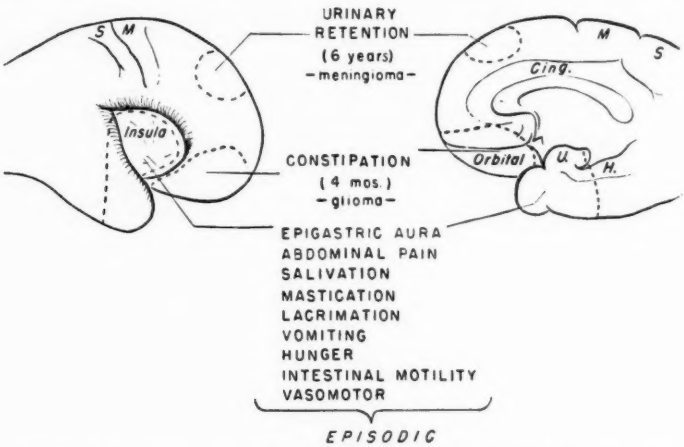

FIG. 1. Visceral phenomena associated with cerebral lesions such as tumor or atrophy at sites indicated. Some of the data represented in the figures have been culled from the work of other investigators (see text)

less of whether or not it was edible. With regard to the psychotic case under discussion, it was felt that if such a lack of discrimination and forced oral examination occurred, these disturbances would probably be transitory.

Operation was carried out in two stages, the 1st stage, on the right, in December 1952, and the second 8 weeks later. On each side the anterior portions of the 2nd and 3rd temporal gyri were removed as far posteriorly as the vein of Labbé. Each resection included the anterior temporal pole, the uncus and the adjacent part of the hippocampal gyri.

Course. Following the 1st operation there was no apparent change in the patient's behavior, habits, speech, or attitude. After the 2nd procedure she was at first extremely negativistic, refusing food, fluids and attention, and not speaking save for an occasional solitary word like "cigarette." In about 2 weeks she began to walk about and eat and talk, but seemed confused. When handed a cigarette during the ensuing month she sometimes lit and smoked it, but on occasions put it in her mouth and chewed it up.

She has gradually become less confused and less subject to abnormal oral intake, and has thus far remained docile instead of assaultive. She has never been incontinent of urine or feces, nor subject to vomiting.

Comment. The temporary postoperative oral reactions, and the lack of incontinence seem strikingly different from the usual effects of bifrontal lobotomy.

3. *Bilateral Fractional Ablations of Frontal Cortex.* In 1947 an extensive study was conducted by the Columbia-Greystone group[19] on the effects of symmetrical bifrontal cortical ablations from different sectors of the frontal lobes in 24 psychotic patients. It should be stressed that visceral disturbances following these operations were *temporary*, lasting 1 to 21 days (Table 1 and Fig. 2).

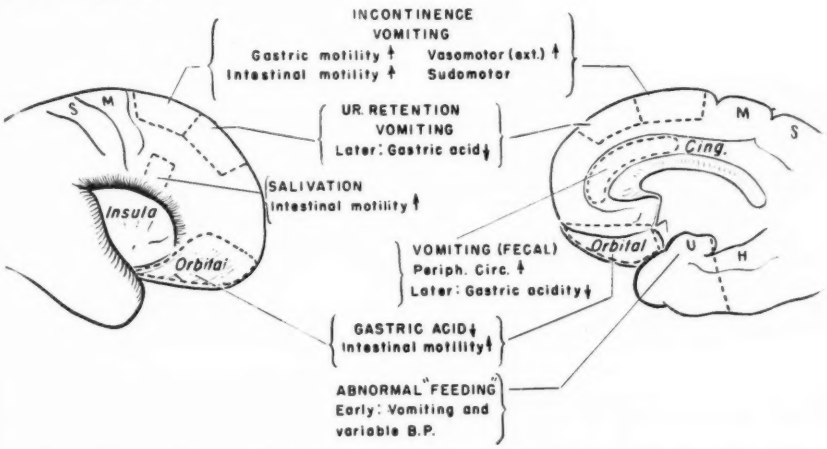

FIG. 2. Visceral effects, usually transitory, following symmetrical bilateral ablation of cerebral cortex at sites indicated. In Case 7 of the series herein reported the resection was unilateral.

For the sake of brevity, ablations are described as to their approximate location in terms of Brodmann's cytoarchitectonic chart.[12] Table 1 summarizes certain groups of patients, such as all those having had removal of a significant part of area 6, under one heading (e.g. urinary incontinence). It should be added that all ablations involving the superior frontal gyri (SFG) or any part thereof also included resection of its medial aspect.

III. ELECTRICAL STIMULATION

Electrical studies were carried out during the course of brain surgery for the relief of mental illness because it was believed that any information so derived might ultimately prove of benefit to that particular patient, as well as to others. At the time these studies were commenced, moreover, relatively little information was available regarding functions of the anterior cingulate cortex and related structures in man. Papez had pointed the way

TABLE 1

*Temporary visceral disturbances following bilateral symmetrical ablations of frontal cortex**

Symptoms	Site of Cortical Ablation (Brodmann's Areas)	
	Immediate Postoperative Period	
Salivation	Area 44 (both cases)	I.F.G.
Vomiting	Area 44	I.F.G.
	Areas 8, 9	S.F.G.
	Area 24 (fecal vomiting)	Ant. Cing.
Intestinal motility (increased)	Area 44 (bloody diarrhea 1 case, several days)	I.F.G.
	Area 11 (1 of 2 cases, diarrhea 1 day)	Subfrontal or orbital gyri
Vasomotor (peripheral circulation improved)	Area 24 (for approx. 2 weeks)	Ant. Cing.
Urinary incontinence	Area 6 (all area 6 cases)	S.F.G.
Urinary retention	Area 8–9 (1 case this series, 3 cases other series; for 3–14 days)	S.F.G.
	Later Postoperative Period	
Gastric motility (faster emptying time)	Areas 6, 8 (also after prefrontal lobotomies)	S.F.G.
(slower emptying time)	Area 24	Ant. Cing.
Gastric acidity (HCl)	No consistent findings	
Gastric acidity (free acid decreased)	Area 9	S.F.G.

* Compiled from Columbia-Greystone Associates.[19] I.F.G. = Inferior Frontal Gyri. S.F.G.-Superior Frontal Gyri. Ant. Cing. = Anterior Cingulate Gyri.

to this type of study in 1937,[68] and subsequent laboratory data[44,100] had lent support to his theory that the anterior cingulate and medial temporal cortex were especially important components of a neural system that participated in the regulations of emotions. Additional laboratory data[21,22,41,80,82,85,87,92,93,104] indicated that these parts of the brain may have a considerable effect on visceral and autonomic functions also. With a view to improving psychosurgical procedures it therefore seemed important to find out whether corresponding regions of the human brain reacted in a similar way.

Source of Data. Visceral or respiratory responses to electrical stimulation of the human cerebral cortex have been obtained in more than 100 cases by the writer and his colleagues.[32,33,78,81,92] Most of these were cases of non-epileptic psychotic patients; 2 were examples of psychomotor epilepsy, while in 1 case (malignant brain tumor) the subtentorial cerebellar cortex was exposed and stimulated (Table 2) after occipital lobectomy.[77]

Data have also been accumulated from other sources. Penfield *et al.*,[74,75] for example, working mostly with epileptics or patients with brain tumor,

TABLE 2

No. of Cases	Site of Stimulation	Type of Response						
		B P	P	Periph. Circ.	Mastication	Lacrimation	G.I.	Resp.
12	Anterior cingulate[81]	↑ ↓	↑↓		+		** ↑	↓ (↑)
75* (+8 more)	Anterior cingulate[92]	↑ ↓	↑↓	↑	+		** ↑	↓
	Posterior orbital	↑ ↓	↑↓					↓
	Anterior temporal	↑ ↓	↑↓		?			↓
	Uncus[33]	↑ ↓	↑↓	↓				↓
3	Hippocampus (intraventricular)					↑		↓
3	Lateral mid-temporal†							↓
4	Paracentral lobule[32]						‡ ↑	0
1	Cerebellum (subtentorial)[77]	↓						0
106								

* These 4 cortical regions were not all stimulated in every case.
** Borborygmi; flatus.
† Cases not yet reported.
‡ Rectal tonus.
Note: The darker arrows indicate the predominate effect.

have elicited epigastric aura from frontal intermediate cortex on the superior mesial aspect of the frontal lobe anterior to the motor cortex (Figs. 1, 3) and from the anterior temporal cortex or the insula. Penfield has elicited no alimentary response from stimulation of other parts of the frontal cortex, including the orbital gyri.[70] Foerster[25] reported singultus and oral movements on stimulation of anterolateral temporal cortex. Chapman, Livingston and Poppen[17,18,53] recorded changes in blood pressure, pulse rate, and respiration on electrical excitation of posterior orbital and anterior temporal cortex, confirmed by Liberson, Scoville and Dunsmore,[50] who obtained similar results, as we have, on stimulating these areas as well as the uncus. These data have been incorporated with ours in Fig. 3.

Technique. In all of our cases electrical stimulation was done with bipolar electrodes 2.5–3.0 mm. apart. Prior to 1949 several stimulators were used.[77,81] Since 1949, when the bulk of this work was done, a stimulator has been employed that delivers a square-wave pulse alterable as to frequency, pulse width and intensity.[32,33,92]

All but a few of our patients have been operated upon under general anesthesia (intravenous pentothal sodium supplemented with intratracheal oxygen-nitrous oxide). Pre-operative medication for these patients, as well

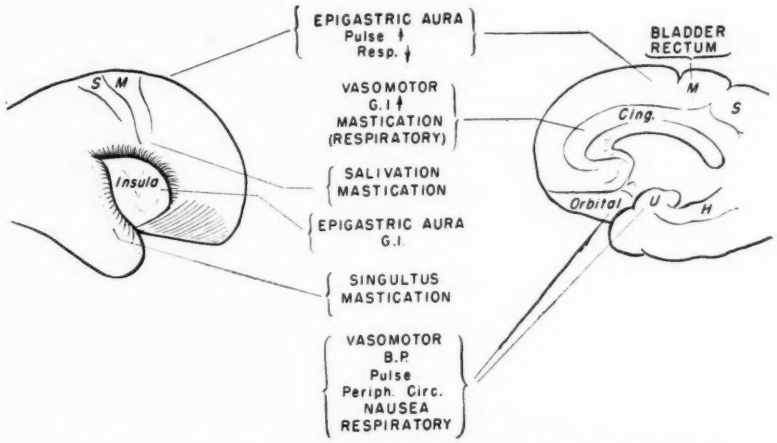

FIG. 3. Visceral and respiratory responses obtained upon electrical stimulation of the human cerebral cortex.

as those operated on under local novocain anesthesia, consisted of morphine sulphate 10 mg. and scopolamine 3 mg. Thus far we have noted no consistent differences in current characteristics required to elicit visceral responses in patients under general anesthesia as compared with those operated upon under local anesthesia only. The operative exposure of cortex was generally achieved by the bifrontal craniotomy flap used for topectomy[78,79] except for the few obviously different types of exposure used for motor cortex or temporal lobe operations.

Stimulation was begun at subthreshold intensities, allowing at least a 1-min. interval between stimuli, which were applied for 15 sec. unless a response was obtained sooner. Control stimulations up to 22 volts were carried out on the convex, ventral and mesial aspects of the frontal and temporal cortex in areas adjacent to those yielding visceral or respiratory responses. These control stimuli did not elicit any observable effects.

Prior to 1949 blood pressure changes were recorded by frequent determinations with a standard cuff aneroid manometer, while respiratory and pulse changes were noted by the anesthetist. Since 1949 continuous blood pressure recordings have been made using the extremely sensitive Lilly capacitometer connected to a needle in the femoral artery. This apparatus also indicated alterations in pulse rate and rhythm.

The respiratory rate and rhythm were continuously recorded by a kymograph attached to an accordion type chest tambour. Changes in the peripheral circulation were recorded by a digital pneumoplethysmograph.

Prior to frontal lobe surgery in a few cases, attempts were made to test the effects of electrical stimulation of the paracentral lobule and adjacent cortex including the cingulate, with regard to bladder tone. Although a water manometer was used attached to an indwelling urethral catheter, no

definite responses were obtained. However, increased rectal tone was noted by digital examination in 2 of 4 patients during stimulation of the caudal extent of the paracentral lobule.

Electrocortical activity (ECG) was studied, using bipolar silver electrodes 2 mm. in diameter and approximately 6 mm. apart. These were placed in pairs close to the stimulated sites as well as on other parts of the fronto-temporal cerebral cortex bilaterally.[92]

RESULTS

The temporary visceral, respiratory, and other effects elicited during stimulation studies by the writer and his colleagues have been described in detail elsewhere,[33,81,92] and are indicated in Fig. 3.

Significant changes in blood pressure lasted 8 to 45 sec. and were generally in the direction of an elevation ranging from 10–20 mm. of mercury, and usually occurred during the 15-sec. period of stimulation, often without other effects such as a change in cardiac or respiratory rate. Occasionally, however, blood pressure changes took place after the cessation of stimulation, but in such cases, since temporary apnea also occurred, the delayed alterations in blood pressure may have been secondary to changes in pulmonary circulation.

The pulse rate was usually slowed by 10 to 20 beats per min. for a few seconds and occasionally extrasystoles were produced. When a striking increase or decrease in finger volume was indicated by pneumoplethysmographic tracings, such changes in the peripheral circulation were also transitory, lasting for only a few seconds. Vasomotor changes were not necessarily associated with respiratory changes as noted below.

Respiratory changes were characterized by apnea lasting 5 to 45 sec. and rarely longer. They were invariably associated with a local electrical after-discharge in the cortex immediately adjacent to the stimulated site, and sometimes occurred during the expiratory, at other times during the inspiratory phase of respiration. Essentially no changes in the rate or rhythm of respirations occurred in any of these tests, responses usually being all (apnea) or nothing. In one early case, however, acceleration of respiratory rate occurred, lasting about 3 min., but this occurred when an unsatisfactory type of stimulator was used.[81] Operative manipulation might also produce such changes.[40,81,90]

Profuse lacrimation was elicited in 1 case (Fig. 4) under general anesthesia on stimulation of the anterior lateral extent of the hippocampus (within the temporal horn of the lateral ventricle). No coincident respiratory changes occurred and there was no pupillary dilatation, although this phenomenon was being looked for. In 2 similar cases lacrimation was not elicited. Stimulation of anterior cingulate cortex in 2 cases was associated with plainly audible borborygmi and in 2 others with violent passage of gas by rectum.

Mid-transtentorial cerebellar stimulation close to the midline was carried

out under local anesthesia in 3 cases prior to 1949 following occipital lobectomy for malignant tumor.[77] In 1 of these cases (Fig. 4) the blood pressure temporarily became unobtainable coincident with cerebellar stimulation, which also yielded phasic leg movements. No changes occurred in the blood pressure in the other 2 cases. This single observation, however, suggests that there is autonomic representation in the cerebellar cortex of man as Moruzzi has shown in animals.[64]

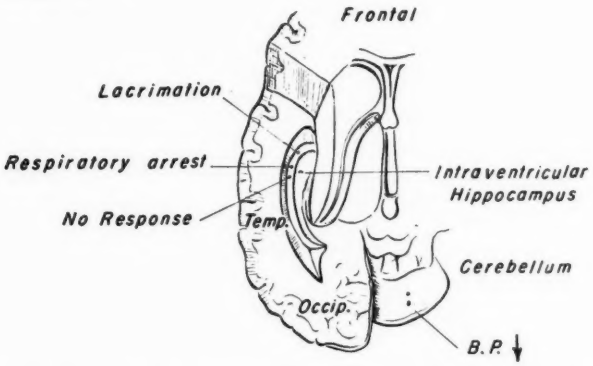

FIG. 4. Visceral responses upon electrical excitation (a) of the intraventricular portion of the hippocampus; and (b) of the subtentorial surface of a cerebellar hemisphere in man.

Pupillary dilatation, which was obtained only upon stimulation of anterior cingulate cortex,[81] is not a visceral response and is therefore omitted from this discussion.

It is important to note that all the responses that have just been described did not occur in any given patient. Certain types of vasomotor responses might occur independently of other types and in the absence of other changes such as apnea. Apnea, on the other hand, was frequently elicited without vasomotor changes, and so on.

It also became clear that stimulation of given points might give rise to only one type of response while stimulation only 2 mm. distant would yield a totally different response. Thus, for example, intraventricular excitation of the hippocampus (Fig. 4) resulted in lacrimation *without apnea* in 1 case, while in the same case with stimulation 2 mm. caudally by the same current parameters, temporary apnea ensued. At 2 mm. further caudally no responses were detected.

Finally it should be stated that effective current thresholds were lowest for the uncus and hippocampus, and comparable to motor cortex thresholds,[32] higher for the anterior temporal and posterior orbital cortex, and highest, as a rule, for the anterior cingulate gyri.

DISCUSSION

The ablation and stimulation studies just reported tend to substantiate many of the clinical observations on cerebral localization of visceral phe-

nomena in man. At the cortical level of both the human and sub-human brain, the most widespread visceral representation appears to be in the limbic system or "visceral brain,"[55–57] which includes the anterior cingulate, anterior temporal and posterior orbital cortex as well as the insula, uncus, amygdaloid nuclei and the hippocampal gyri. Anatomical studies[5–7,15,26,31,76,86,97] electrical stimulation,[9,39,41,45,53,57,87,93] and the spread of electrically induced after-discharge,[49,57,83,92] indicate close structural and functional linkage of these component parts of the visceral brain. Its importance in emotional as well as visceral control[33,56,68,72] makes the visceral

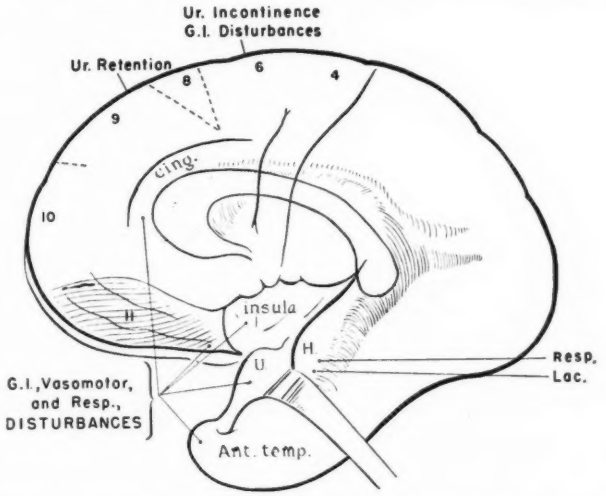

FIG. 5. Composite diagram indicating visceral representation by the human cerebral cortex as revealed by the effects of pathological lesions, surgical ablations, and electrical or mechanical stimulation. The numerals refer to Brodmann's areas (see text). U = uncus. H = hippocampal gyrus. Cing. = anterior cingulate gyrus. Ur. = urinary. Lac. = lacrimation. The shaded zone near left lower corner of diagram indicates orbital gyri or subfrontal cortex while the remaining shading suggests the position of the lateral ventricles.

brain or limbic ring[57] therapeutically significant with regard to psychosurgery, and diagnostically significant with regard to earlier localization of intracranial lesions.

Laboratory data described by Anand and Brobeck[3] and MacLean,[57] together with some of the clinical data reported above, suggest the probability of even more discrete localization of many important visceral and emotional functions in the human brain than indicated thus far. Further investigations should prove of great value.

The temporary nature of visceral symptoms following cortical ablations in animals[13] and man indicate that other remaining parts of the brain (not necessarily part of the limbic system or visceral brain) also regulate some of these functions, as illustrated by the widespread cerebral representation[1,27,96] of autonomic regulation, the fact that gastric aura may be elicited from

frontal intermediate cortex[75] as well as from the insula and anterior temporal cortex, or that the peripheral circulation may be influenced not only by portions of the visceral brain, such as the uncus and anterior cingulate cortex (cf. above), but also by the motor and premotor cortex.[14]

As to control of the urinary bladder, it appears that incontinence or retention of urine may depend rather on the localization of bilateral superior frontal ablation (cf. above) than on a shock factor,[47] although more study is needed to settle this point. The posterior extent of the superior frontal gyri also seems to be important in regulation of gastric and intestinal motility as indicated by ablation studies, some of which were preceded and followed by barium meal studies.[19] Gastric acidity may likewise be altered by ablation of frontal cortex, particularly of posterior orbital or posterior superior frontal gyri.[16,19] These findings are in keeping with laboratory data indicating gastro-intestinal regulation by frontal cortex in animals.[4,9,24,35,61,102] Perhaps there is a relation between these findings and the occasional occurrences of a gastric ulcer after frontal lobotomy,[54] relief of ulcerative colitis by topectomy (personal observation), or gastric hemorrhage in association with intracranial lesions.[43,84]

With further regard to alimentary functions it is pertinent to mention taste and the sense of smell. It has of course been made clear by Papez,[68] von Bonin[11] and others that while olfactory perception is represented in the medial anterior aspect of the temporal lobes, this rhinencephalic portion of the brain is by no means exclusively concerned with the sense of smell but deals also with visceral and emotional functions. While disturbances of taste may be caused by deep temporal lobe pathology, Shenkin and Lewey[91] and von Bonin[11] pointed out that taste may be represented in the lower parietal sensory cortex of man as in the corresponding cortical area of the primate brain[14] and the related portion of the thalamus.[69]

Parenthetically it may be worth noting that vasomotor changes may be induced by stimulation of the cerebellar cortex in man[77] as in animals[64] and that piloerection may be represented in the frontal cortex in man.[51] It may be ultimately found, furthermore, that all cortically represented visceral functions have specific areas for activation and adjacent areas for inhibition, as demonstrated for other phenomena[28,58,101] and many autonomic functions.

Since the subcortical localization of visceral functions is beyond the scope of this discussion, the reader may be referred to the summaries of Fulton[27] and Hess,[34] the work of Wang[67,98,99] on medullary centers for salivation and vomiting in cats, and White's [103] account of autonomic disturbances upon electrical stimulation of the hypothalamus of man.

Subcortical connections between the frontal and temporal cortex to the thalamus, hypothalamus, brain stem and spinal cord have been demonstrated in laboratory animals[2,15,26,42,46,59,60,82,86,94,96,97] and man.[10,38,62,63,10] The complexity and close juxtaposition of many of these fibre paths make accurate application of this knowledge, as in psychosurgery for example,

difficult if not impossible with present techniques. Obviously there is need for further study.

As to emotional changes effected by isolation or ablation of parts of the visceral brain, these have usually been beneficial, as emphasized by several writers with reference particularly to the anterior cingulate[48,52] and orbital gyri[19,79,89] in psychotic patients and the anteromedial temporal cortex in cases of psychomotor epilepsy.[8,30,72] The effects of medial temporal isolation[90] or ablation[95] on emotional reactions in man, however, are not as striking as in animals,[44] perhaps because present knowledge and techniques do not permit sufficiently accurate pinpointing of crucial structures. The fact that juxta-limbic lesions, such as certain temporal lobe lesions or those effected by frontal lobotomy or topectomy, may result in visceral and/or emotional changes[66] may in part be caused by a "release" phenomenon exerted on the adjacent closely related limbic system. It is also possible that visceral or emotional effects may be masked or cancelled by simultaneous juxta-limbic surgical procedures if it can be assumed that both an effector and inhibitor function may be sacrificed simultaneously.

SUMMARY

1. Pathological and surgical lesions, together with electrical studies of the cerebral cortex, have been described with regard to efferent and afferent visceral representation in the human brain.

2. These observations suggest that the "visceral brain" or limbic system has essentially the same general structure, properties and functions in animals and man.

3. Visceral representation in man is also found in non-limbic cortex, and is prominent in the motor and premotor cortex.

4. The fragmentary nature of the data described indicates the need of further study.

5. The importance of some of these observations with regard to psychosurgery is mentioned.

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THE LIMBIC LOBE IN MAN*

W. B. SCOVILLE, M.D.†
Hartford, Connecticut

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IN OPENING this discussion,‡ I wish to extend congratulations to Drs. Pool and MacLean for the meticulous and painstaking collection and presentation of data. Their work begins to be monumental. Dr. Pool and his associates are embarked in collecting from known cortical areas a vast accumulation of physiologic and behavioral data similar to that impressive work already accomplished on animals by Dr. Fulton's associates, especially Dr. MacLean. Their respective works will sow seeds for future as well as present knowledge.

For the past four years in Hartford, we have been embarked on a study of the limbic area in man, which, as you know, includes the rhinencephalon, the anterior cingulate, and posterior orbital cortices. We have isolated, by the "undercutting" technique, the anterior cingulate gyrus and the posterior orbital cortex in a series of fractional lobotomies performed on schizophrenic and neurotic patients. More recently, we have both stimulated and resected bilaterally various portions of the rhinencephalon in carrying out medial temporal lobectomies on schizophrenic patients and certain epileptic patients. I speak with all humility of the small bits of passing data we have accumulated in carrying out these operations on some 230 patients.[4,5]

Cingulate and Orbital Areas. Stimulation of the anterior cingulate and posterior orbital regions has given meager results.[2] Cortical isolation of the rostral cingulate gyrus and the orbital cortex, respectively, has resulted in appreciable improvement in some 50 per cent of schizophrenic psychoses, roughly approximating the results obtained in standard lobotomies. Orbital isolation has given a most gratifying improvement in depressions, psychoneuroses, and tension states without any gross blunting of personality.[3] Following these undercuttings, there were no other changes in personality except for some lightening of mood and a distinct increase in libido in certain cases of orbital undercutting.

Medial Temporal Areas (Rhinencephalon). Uncal stimulation gave marked results with respiratory arrest, loss of consciousness, and clinical or electric seizure formation. Bilateral resection of the uncus and amygdalum alone,[2,4] or in conjunction with the entire pyriform amygdaloid hippocampal complex, has resulted in no marked physiologic or behavioral changes with

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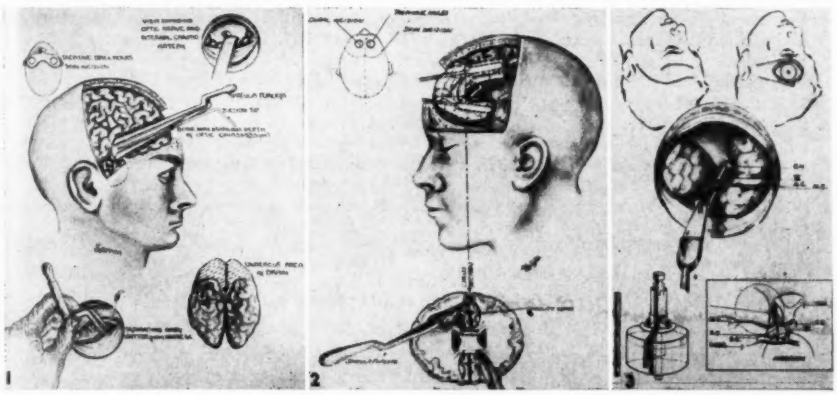
† 85 Jefferson Street, Hartford 14, Connecticut.

‡ This discussion is based on work accomplished jointly with R. H. Dunsmore, C. E. Henry and W. T. Liberson, E. K. Wilk and A. J. Pepe.

the one exception of *a very grave, recent memory loss,** so severe as to prevent the patient from remembering the locations of the rooms in which he lives, the names of his close associates, or even the way to toilet and urinal. There has been no apparent increase in libido or sexual activity, no remission of auditory hallucinations, and no gross rage reaction. A temporary calming reaction, similar to that found after other fractional lobotomies, occurred. Hallucinations of smell were not apparent following uncal stimulation. Vomiting and temporary loss of consciousness occurred commonly during manipulation of the uncal region, but following resection they disappeared.

Electrocorticography. ECGs of the cingulate and posterior orbital gyri[1] were not remarkable. The resting uncus exhibited an ECG quite different from all other frontotemporal cortical areas studied. Following stimulation of the uncus, focal seizure patterns with afterdischarge resulted, spreading to the orbital and contralateral uncus but not to the superior frontal convexity.

Mental Changes. Psychiatric changes were meager and largely quantitative after medial temporal resections, being exceptional only in a schizophrenic patient in whom 9 cm. of the medial surface cortex of the temporal



FIGS. 1–3. Illustrating the three areas studied in the limbic lobe complex.
(1) Orbital. (2) Cingulate. (3) Medial temporal.

lobes had been removed bilaterally. *Of considerable interest has been the psychiatric result obtained by inadvertent damage to midline structures in the region of the hypothalamus and midbrain in three patients.*

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* This loss was apparent in the 2 patients undergoing bilateral resection of the entire complex including the hippocampal gyrus extending posteriorly for a length of 8–9 cm. from the tips of the temporal lobes.

Addendum. An additional 2 patients with sphenoid ridge meningioma and aneurysmal temporal lobe clot were subjected to unilateral nondominant inferior temporal lobectomy with deliberate resection of the hippocampal complex because of incisural hippocampal herniation from malignant edema. These 2 patients continue to show grave loss of memory at 2½ years and 6 weeks postoperatively, respectively, without any impairment of deductive reasoning, suggesting a relationship between these areas and recent memory, although both patients obviously had diffuse damage from edema.

Epilepsy. In line with the observations of Gibbs, Bailey, Jasper, and Penfield on the prevalence of medial temporal lobe seizures and the known epileptogenic quality of the uncus to stimulation, an interesting query comes to mind—could bilateral resection of such known epileptogenic areas as the uncus raise the threshold for all fits, as do pharmaceutical anticonvulsants?

In conclusion, it is our belief, or perhaps I should say fantasy, that the limbic lobe of man may not yield up the secrets of smell, or of auditory hallucinations, or of fundamental mechanisms of mental disease and of epilepsy. However, continuing limbic lobe studies may bring us one blind step nearer to the location of these deeper mechanisms. Who knows but that in future years neurosurgeons may apply direct selective shock therapy to the hypothalamus, thereby relegating psychoanalysis to that scientific limbo where perhaps it belongs? And who knows if neurosurgeons may even carry out selective rhinencephalic ablations in order to raise the threshold for all convulsions, and thus dispense with pharmaceutical anticonvulsants?

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THE MECHANISM OF NEUROLOGICAL SYMPTOMS AND SIGNS IN SPONDYLOLISTHESIS AT THE FIFTH LUMBAR, FIRST SACRAL LEVEL

ROBERT DEAN WOOLSEY, M.D.*
St. Louis, Missouri

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NEUROLOGICAL symptoms and signs are variable in spondylolisthesis of the 5th lumbar on the 1st sacral segment. According to Meyerding[7] sciatic pain is not common unless there is a protrusion of an intervertebral disc. He found that the association of backache and sciatic pain was more common among males than females: 78.8 per cent to 21.2 per cent. A total of 18 cases of sciatica—10 unilateral, 8 bilateral—were found by Guri[4] in his series of 60 cases. Three patients had numbness and paresthesia of lower extremities; 2 had abolished Achilles reflex bilaterally. Signs of nerve root compression were noted by Macnab[6] in 11 patients. The ankle jerk was absent in all of them, and the knee jerk was absent in 2. One patient had anesthesia in the distribution of the 4th lumbar dermatome, and 2 showed marked weakness of the quadriceps, tibialis anterior, and tibialis posterior. In 1 patient who had never suffered from backache or sciatica the presenting symptom was a dragging of the left foot.

As to the cause of pain in spondylolisthesis, Kleinberg[5] called attention to the fact that the laminar defect in a pre-spondylolisthesis of the 4th or 5th lumbar vertebra is close to the lumbar nerve roots. Consequently, when the connective tissue bridging the bony hiatus is injured, the resultant hemorrhage and edema may irritate the nerve roots. Macnab[6] spoke of displacement of the vertebra forward associated with narrowing of the two inferior intervertebral foramina. The osteoarthritis which occurs in the articular joints may be associated with marked capsular thickening, and occasionally there is spur formation on the posterior edge of the displaced vertebral body. Any one or all three of these factors may play a part in root compression. Macnab also thought that the roots may be compressed by the lamina of the displaced vertebra or by an associated prolapsed intervertebral disc.

Low back symptoms in patients with spondylolisthesis are probably caused by narrowing of the intervertebral disc and arthritic changes in the lumbosacral articulation, Caldwell[2] stated, rather than by progressive displacement of the spinal column with consequent drag upon the supporting ligaments.

* 16 Hampton Village Plaza, St. Louis 9, Missouri.

The classical treatment of spondylolisthesis has been lumbosacral fusion by either the Hibbs or Albee method or some variation or combination of the two. Myerding's[7] results with fusion in 118 patients are recorded as good in 60.1 per cent; improved in 28 per cent; and unimproved in 11.9 per cent. Guri[4] reported 69.2 per cent of good results in 39 patients treated by spinal fusion, and only 41.1 per cent in 34 patients treated by conservative measures. Briggs and Keats[1] emphasized the poor results obtained with conservative treatment. They presented 18 patients operated on for the relief of backache and leg pain associated with spondylolisthesis. In 9 patients with no history of leg pain and no evidence of root compression, the operation consisted of laminectomy of the affected vertebra with subsequent Hibbs type of fusion. In the other 9 patients with nerve root involvement and severe pain in the legs, a thorough exploration of the intervertebral foramina was necessary. In addition to the laminectomy and chip fusion, the authors performed a foraminotomy of the roots compressed on the side of the sciatic pain or bilaterally if there was pain in both legs. When they removed the roof of the foramen with a sharp osteotome and curette, the nerve root seemed to bulge out and expand. The exposed roots were covered with fat grafts. Performing a Hibbs fusion in routine manner, they were careful to cover the area of the exposed dura mater and roots with small, flat bone chips. They found a disc protrusion in only 1 of the 9 patients with sciatica. These authors stated that a fusion is always necessary and have obtained good results in 18 patients operated on.

SYMPTOMS

Low back pain is usually the first symptom in spondylolisthesis. This low back pain may be severe and is often disabling and chronic. A trifling injury may bring on acute pain. Besides low back pain, unilateral or bilateral sciatic radiation is common in the more severe degrees of the disease. Sometimes the pain will be so predominantly unilateral that one suspects the presence of an intervertebral disc lesion. The pain may radiate along the course of the sciatic nerve to the foot and may be increased by coughing, sneezing, and straining at stool. Forward bending and straight leg raising are likewise painful.

PHYSICAL FINDINGS

The physical findings depend largely on the degree of spondylolisthesis. There may be no neurological findings, and diagnosis may depend entirely upon x-ray. In the more advanced degrees of spondylolisthesis, there is a definite offset; the 5th lumbar spine is displaced over the 1st sacral so that one can feel a definite ledge when he examines the patient in the upright and flexed positions. Signs of bilateral or unilateral compression of the 5th lumbar and 1st sacral roots are often present. They consist of weak or absent ankle jerks, hypesthesia over dorsum of foot and lateral aspect of the calf and atrophy and weakness of lower leg musculature.

MECHANISM OF THE NEUROLOGICAL SYMPTOMS AND SIGNS

The importance of the fibrous isthmus of the neural arch at L5 and S1 in the diagnosis of spondylolisthesis and pre-spondylolisthesis was pointed out by Galluccio.[3] There may be concomitant spina bifida or a failure of the upper articulating facet of the 5th lumbar lamina likewise to fuse with the lamina. The back pain has been attributed to abnormal pull on the articulating facets of the 5th lumbar lamina with the 1st sacral segment. Sciatic pain has customarily been attributed to compression of nerve roots or to concomitant intervertebral disc lesion of L5-S1. I have done numerous explorations for intervertebral disc lesions in patients with spondylolisthesis in conjunction with orthopedic colleagues. I have never encountered a lesion of the intervertebral disc. I have talked to numerous orthopedic surgeons, and none of them has seen such a lesion. Briggs *et al.*[1] reported 1 case out of 25 with a disc lesion.

My attention was first called to the causative mechanism of the neurological symptoms and signs in the first patient on whom I operated, Mrs. C. E. (Case 1). This woman had a severe Grade IV spondylolisthesis with marked bony reaction and spur formation about the intervertebral disc of L5 and S1. At operation I found that the lamina and spine of L5 were freely movable. After cutting the ligaments of the facets between L5 and S1 and cutting the interlaminal ligaments of the facets between L4 and L5, the fibrous isthmus between the lamina and pedicle of L5 could then be cut. The intact specimen could then be completely removed. At this point, I could see that this lamina of L5 had been pulled downward by the slipping forward of L5 body on S1. There was definite compression of L5 and S1 roots which was obviously accentuated in the erect position by wedging forward of the 5th lamina, spine and inferior facets between the spine and lamina of the 4th lumbar and 1st sacral segments. This compression is demonstrated in Fig. 1. This has been my experience in all patients operated upon thus far, whether it be a pre-spondylolisthesis (Fig. 2) with a completely fibrous isthmus and a freely movable spine and lamina of L5, or a severe 3rd or 4th degree forward displacement of L5 on S1 (Fig. 1).

The reason spinal fusions have not been particularly successful in the treatment of spondylolisthesis is related to the freely movable lamina and spine and inferior articulating facets of lumbar 5 vertebra. This lamina with the spine and facets serves no useful purpose since it is freely movable, and is attached to the pedicle, to the sacral facets, and to the lamina and facets above by fibrous tissue only. I believe that the spine, lamina, and facets of L5 should be removed at laminectomy with dissection of the pedicle on either side of L5 vertebra so that the lumbar 5 and the 1st sacral roots are perfectly free. This procedure, I think, will relieve the postoperative morbidity and pain that are common after lumbosacral fusion. I believe that patients with pre-spondylolisthesis, i.e., with an isthmus defect demonstrated by x-ray, will be completely relieved in most instances with removal of the lamina and facets of L5 without spinal fusion. In individuals with

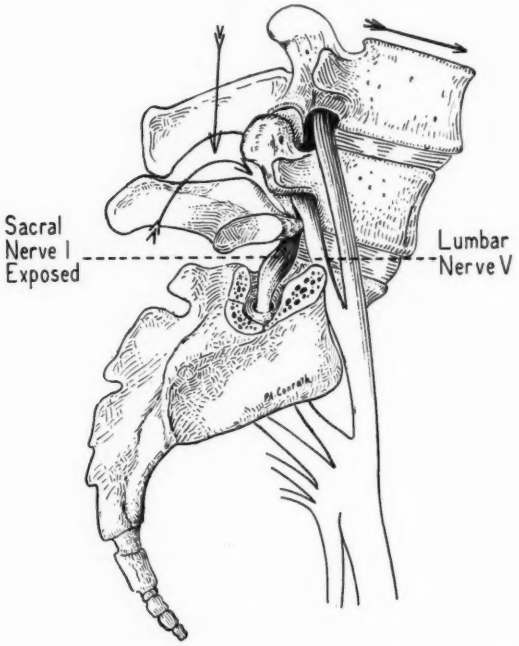

FIG. 1. Dissection of lumbosacral area in a 1st degree spondylolisthesis, showing the impingement upon the 5th lumbar and 1st sacral roots of the freely movable 5th lumbar lamina and spine, and the accentuation of this impingement when the individual assumes the erect position.

Grade II and III spondylolisthesis, complete and permanent relief may quite possibly be obtained by similar measures, although the patients should be observed carefully for any further progression of the disease so that fusion can be instituted if necessary. In patients up to 25 years of age, I believe spinal fusion should be done to prevent further slipping. In the older age group there is usually a marked amount of bony proliferation about the disc space of L5 and S1, and frequently there is an arthritic fusion of lumbar 5 and sacral 1 bodies before the patient reaches the surgeon.

CASE REPORTS

Case 1. Mrs. C.E., a 69-year-old woman referred by Dr. John Hayward, was admitted to Missouri Baptist Hospital on Jan. 11, 1950, and was discharged Jan. 30, 1950.

Her chief complaint was a shooting pain in the left lower extremity since May, 1949. In May, 1949, she had a fall. Afterwards, she experienced low back pain and bilateral sciatic pain, particularly when walking. During the last few weeks she had noticed some numbness of the lateral aspects of her lower limbs and some weakness of dorsiflexion of both lower extremities.

Examination. There was limitation of forward bending and of straight leg raising bilaterally. There was hypesthesia over the outer aspect of both calves and the dorsum of the foot. There was weakness of dorsiflexion of both feet. The ankle jerks and knee jerks were absent.

X-rays of the spine showed a marked spondylolisthesis with 1 cm. of anterior displacement of L5 on S1. There was also a moderately advanced osteoarthritis. A myelogram was negative.

Operation. On Jan. 20, 1950, an incision was made over L4 and 5 and S1 spines and the muscles were separated free bilaterally to the extent of the articulating facets. The spine and lamina of L5 were freely movable and the isthmus was obviously fibrous. Accordingly, the ligaments holding the lower facets were incised, and the spine and lamina of L5 were removed. The pedicle was carefully dissected so that the nerve roots at L5 and S1 were completely decompressed out into the root canals.

Course. Following operation this patient has done very well and at the present time (3 years later) is completely free of pain.

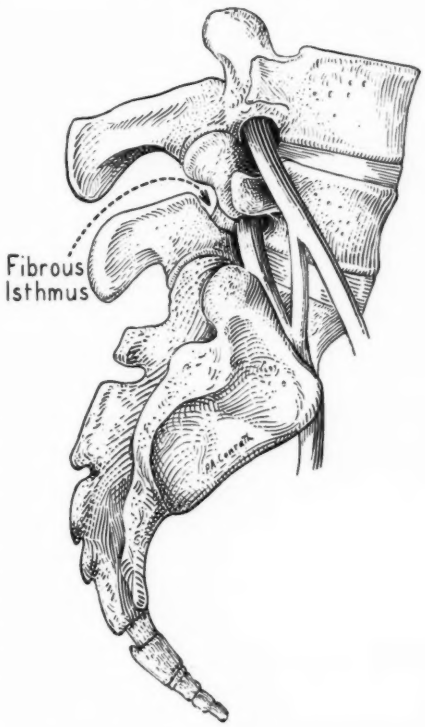

FIG. 2. Lateral view of lumbosacral area demonstrating the lesion encountered with a prespondylolisthesis, and showing the proximity of the 5th lumbar nerve root to the freely movable lamina and spine of L5.

Case 2. Mr. C.W., a 48-year-old white man, was admitted to Firmin Desloge Hospital on July 13, 1951, and was discharged on Aug. 22, 1951.

His chief complaints were pain in the left sacroiliac area, pain in both legs, and weakness in the left leg.

Two years before admission, the patient first felt numbness of the left leg and foot while pushing a lawnmower. The numbness lasted for more than a month, then cleared spontaneously. In March, 1951 the numbness returned, and he had some loss of balance. During the week before he was admitted to the hospital, his symptoms became much worse and he first noticed marked weakness of the left leg.

His past history revealed that he had had a gastroenterostomy at the Park Lane Hospital for a gastric ulcer, and his recovery was complicated by a postoperative ventral hernia.

Examination. The patient was an emaciated individual, in good physical vigor. He had an ataxic gait and tended to evert his left foot. The abdominal reflexes were negative; cremasteric reflexes were positive. There was hypesthesia of the left foot

and ankle, both dorsal and plantar surfaces. The position sense was absent in the left great toe. The deep reflexes at both knee and ankle were absent. The back was tender over L3, 4 and 5. There was atrophy of the left leg and thigh and weakness of adduction and internal rotation of the left leg.

X-rays of the spine showed marked hypertrophic spondylitis in the lumbar spine with a fusion of L2 and 3, with absence of the disc at this level. There was an anterior displacement of the last lumbar vertebra in relation to the sacrum, or spondylolisthesis.

Operation. On July 17, 1951, the spines and laminae of L4, L5 and S1 were exposed laterally to the facets. The isthmus of L5 was fibrous and the lamina was freely movable. The lamina and spine were removed and the rudimentary pedicle was dissected with a sharp curette. The nerve roots at this level were freed entirely and considerable arachnoiditis was noted both inside the spinal canal and about the roots. No effort was made to remove these adhesions; the spinal canal was left open and a piece of gelfoam was placed over the open dura mater.

Course. The patient had a very rough postoperative course and an intestinal obstruction developed which gradually cleared by the aid of Wangensteen suction. It was finally necessary to do a jejunostomy for feeding. The patient since then has had his gastroenterostomy taken down and is in need of a resection of the stomach for his gastric ulcer. On Aug. 23, 1952 the orthopedist stated that the patient had no back pain, no tenderness, and no weakness.

Case 3. L.E.D., a 15-year-old white boy, was admitted to Firmin Desloge Hospital on Dec. 12, 1952.

His chief complaint was pain in the lumbar area of 1 year's duration. In December, 1951, a year before admission, the patient "felt something pull in his back" as he shot a basket in a basketball game. For the next 2 weeks he had a stiff back and felt vague, undefined pains along the outer aspect of his left thigh. He was not greatly disabled, but his back continued to become more stiff during the next 2 to 3 weeks. The pain began to radiate down the posterior aspect of the left thigh.

In December, 1951, he was taken to Memphis, where he was told that he had a ruptured intervertebral disc. A brace somewhat relieved his back pain, but the shooting pain in the leg continued to get worse and the whole lower back seemed "tied in a knot."

Examination. The patient stood cautiously and favored the left leg. When walking he tended to drag the left leg. When he lay on his back, he tended to hold the left leg flexed and externally rotated. When standing, there was an obvious pelvic tilt, with the right higher than the left by 1½ inches. There was a scoliosis of the dorsal spine to the right. All muscles in the lumbosacral and dorsal area were spastic, and there was tenderness in the lumbosacral area. The left leg was smaller than the right; the gastrocnemius on the left measured 28 cm., on the right 28.75 cm.; midthigh 45 cm. on the left, 46 on the right. The knee jerks and ankle jerks were weak to absent on the left, and present and active on the right. Sensation was decreased over the anterior aspect of the left thigh, and the plantar and dorsal aspects of the left foot. There was weakness of plantar flexion and dorsiflexion of the left foot.

Operation. A wide exposure of the spines and laminae of L4, 5 and S1 to the facets was made on Jan. 6, 1953. The lamina and spine of L5 were freely movable on the pedicle. After incising the ligaments holding the facets, the lamina and spine were

removed. Then the rudimentary pedicle was dissected with a curette, and the nerve roots at the 5th space were completely freed on both sides. The disc space was then entered and curetted bilaterally to completely remove all disc material. An unsuccessful effort was made to reduce the dislocation, and at this point Dr. Robert O'Brien entered the operation and did a classical Hibbs' type of fusion.

Course. Following operation, the patient had a little difficulty in voiding for a few days. He had a little fever (101–102°) for 48 hours. Except for this, his postoperative course has been uneventful.

At this writing (Feb. 23, 1953) the patient is up and about with a cast, and states that he has had no pain in his legs or back since operation. The hypesthesia has disappeared. The ankle jerks are again equal and active.

X-rays of this boy's back taken preoperatively showed a definite 3rd to 4th degree spondylolisthesis with marked forward dislocation. Following operation, x-rays of the lumbar spine likewise have shown the dislocation forward of the 5th lumbar on 1st sacral vertebrae.

Case 4. Mr. L.E.B., a 44-year-old white man referred by his attorney, was admitted to St. Mary's Hospital on Nov. 20, 1952.

His chief complaint was pain in the back and pain down the leg. The patient was helping to lift a piece of pig iron from the rear end of a truck while at work. The iron slipped; the man caught it. Although he was pulled over backwards, he did not fall. He got the iron into the truck, but he felt something snap in his back. He continued to work that day, delivered his truck order, and he told his foreman that he had hurt his back. He delivered one more load and sat down to relax, and then he couldn't get up. Although injured in July 1951, the patient kept working until the next March. Then he entered Missouri Baptist Hospital where a myelogram was done and x-rays were taken. Nothing could be found to indicate the cause of his trouble, and he was given a belt to wear.

When questioned, he said that the pain was centered low in his back, that it radiated into the right hip joint and sometimes went as far as the back of his knee. The pain was definitely increased on coughing or sneezing.

Examination. There was limitation of straight leg raising on both sides, more pronounced on the left, and limitation of forward bending. Ankle jerks were weak to absent bilaterally. There was hypesthesia over L4 and 5, more marked on the left. A second myelogram was also negative. The total protein was normal.

Course. After consulting the company attorney, the patient was dismissed from the hospital and sent to Dr. H. R. McCarroll for consultation with the recommendation that an exploration be done for a possible ruptured intervertebral disc not visualized by myelography. Dr. McCarroll agreed that the man should be explored. On Jan. 14, 1953, he was readmitted to St. Mary's Hospital.

Operation. On Jan. 31, 1953, with the patient under ether anesthesia, the usual unilateral exposure of the space between L5 and S1 and between L4 and L5 was done The nerve roots were inspected and retracted medially, and the disc spaces were found to be entirely normal. A bilateral exposure was then done. As the operation progressed and more and more ligaments were cut, it became obvious that the lamina, spine, and facets of L5 were completely movable on the pedicle, and that we were dealing with a pre-spondylolisthesis. Accordingly, the ligaments connecting the lower facets of L5 to the sacrum were cut; the interlaminal ligaments were re-

moved bilaterally above and below this lamina, and then by retracting the spine upward we were able to cut the fibrous isthmus and remove the lamina and spine of L5 intact. The 5th lumbar and 1st sacral roots were then completely free.

Course. After operation this man improved rapidly. He said on the following day that for the first time since injury he had relief of the pain in his legs. He left the hospital on the 7th postoperative day after removal of his sutures. His leg pain gone, he is now ready to return to work.

Case 5. Mr. G.E., a 35-year-old white man, referred by Dr. Eugene Dmytryk, St. Louis, was admitted to St. Mary's Hospital on Feb. 10, 1953. His chief complaint was that for 3 years he had had a pain in the back with radiation down the left leg. The pain first developed in the lower back to the left of the midline, radiating down the left leg. It was constant, intermittent in severity, and extended as far as the back of the foot. It was accompanied by tingling and numbness of the foot, but there was no anesthesia. The patient tended to limp and to drag his left leg. Heat and cold to the back of the leg helped somewhat. He had been able to work, was told that he had a ruptured disc, and operation was advised. He had refused the operation.

Examination. He was a somewhat obese white male. He had marked tenderness over the lower lumbar spine. There was limitation of straight leg raising bilaterally, particularly on the left. There was limitation of forward bending. There was a hypesthesia of L4 and 5 on the left. The ankle jerks were bilaterally absent. The knee jerks were equal and active. X-rays of the lumbar spine showed no subluxation at L5 on S1, but there was a definite narrowing of the isthmus of L5 bilaterally. A diagnosis of pre-spondylolisthesis was made. A myelogram was negative. The total protein of the spinal fluid was normal in amount.

Operation. On Feb. 17, 1953, the muscles were separated free from the spines and laminae of L4, 5, and S1 out as far as the articulating facets. The spines and laminae of L5 and S1 were freely movable and obviously attached to the body of L5 by merely fibrous union. The ligaments of the lower articulating facets were cut together with the ligamentum flavum above and below L5. The lamina, spine, and facets were removed, and the rudimentary pedicle of L5 was dissected bilaterally with a curette. The nerve roots were completely freed out into the nerve root canals.

Course. Since the operation, the patient has had no pain and is now ready to return to work.

Case 6. Mr. C.R.G., a 29-year-old white man referred by Dr. James Shy of St. Louis, was admitted to Missouri Baptist Hospital on Feb. 2, 1953. He complained of a pain very low in his back, a pain which radiated down the back of his left leg. He said that the leg would fall asleep and that numbness would start in his foot and go up the side of his leg. There was no definite history of back injury, although he stated that he had hurt his back slightly while moving furniture. He had had back pain for several years. A member of the Merchant Marine, he was seen at Marine Hospital in New York where he had an attack of back pain. No measures were prescribed for its relief.

Examination. There was slight limitation of forward bending and of straight leg raising. There was hypesthesia over L5 and S1 dermatome on the left side. The ankle jerk of the left was slightly diminished as compared with that of the right, and both were inactive as compared with the knee jerk. There was tenderness of the lower back.

A myelogram was entirely negative. X-rays of the lumbar spine showed a spina

bifida occulta of the 5th lumbar spine and lamina. There was a definite spondylolisthesis, and the pedicles of L5 were rudimentary. A defect was seen in articulation on the right but was not definitely demonstrated on the left.

Operation. A laminectomy was done on Feb. 25, 1953. When the lamina and spine of L5 were exposed, both were rudimentary and small; both could be moved freely and independently. On dissecting free the ligaments between L5 and S1, the disc was normal on both sides, as it was at the L4-L5 interspace. The spine and lamina, on either side of the midline, were cut free from the pedicles with sharp dissection. When the spine and lamina were removed on either side together with the facet of the lamina which joined the 1st sacral segment, one could see that there had been pressure downward and inward on the 1st sacral ganglia which lay just medial to the sacral articular facets. Most of the pressure had obviously been on the 1st sacral roots and ganglia; there had also been pressure on the 5th lumbar root as it went around the pedicle at this level.

Course. This man has had complete relief of his leg pain since operation.

Case 7. Mrs. K.G., a 37-year-old white woman, was referred by her husband. When first seen on Feb. 21, 1953, her chief complaint was low back pain. On Feb. 6, 1953, while bending over a table to give inoculations to children, she said she had difficulty straightening up. She had pain in her lumbosacral region, but there was no radiation to her legs. There was a definite increase in pain on coughing. She had had considerable low back pain for several years, and on occasion it had responded to osteopathic manipulation. At times she had had pain in her left hip.

Examination. Ankle jerks were hyperactive and equal. Knee jerks were equal and active. There was no hypesthesia and no atrophy. There was no limitation of motion of the low back. There was some limitation of forward bending, but no limitation of straight leg raising.

Roentgenograms of the lumbar spine showed a 1st degree spondylolisthesis with fibrous pedicles bilaterally. There was a failure of fusion of the neural arch of the 5th lumbar vertebra on the right side. The anterior articulating facet of the 4th lumbar vertebra on the right side was smaller and not as well developed as the one on the left.

Myelography was done, using 9 cc. of pantopaque. Films were taken in anteroposterior, lateral, and both oblique projections, with the spine in flexion and extension. This demonstrated the defect of the isthmus on both sides of the 5th lumbar region.

Operation. The findings were similar to those described in the other patients.

Course. Postoperative relief was immediate, and the patient has already returned to her work in public health nursing.

DISCUSSION

Follow-up on these patients is of too short a duration to be conclusive. However, in Case 1, a 69-year-old woman with a Grade III spondylolisthesis, there has been complete relief of pain and symptoms since the time of operation more than 3 years ago. The same was true in Case 2, a 48-year-old man.

Case 3, a 15-year-old boy, has had complete relief of symptoms since operation. His ankle jerks have returned to normal, and the hypesthesia noted before operation has completely disappeared. He is now up and about

with a cast, and I believe that with the spinal fusion he should have complete and permanent relief.

Case 4 is also worthy of note. This patient was first suspected of having a ruptured intervertebral disc; and when the myelogram was negative it was thought that the man was neurotic. He was explored with a preoperative diagnosis of possible ruptured intervertebral disc. During the operation, the definite pre-spondylolisthesis was found. Subsequent re-examination of the x-rays revealed a slight forward slipping of L5 on S1. He has had complete relief of pain since the first postoperative day.

It is not within the scope of this paper to enter the discussion as to the etiology of spondylolisthesis. There are two schools of thought, one regarding it as a congenital affair and the other as of developmental origin. The arguments for both views are good but do not necessarily concern us.

SUMMARY

Seven operations have been done on patients with varying degrees of spondylolisthesis, from a pre-spondylolisthesis with merely a fibrous isthmus to a 3rd and 4th degree spondylolisthesis. These patients have been completely relieved of pain postoperatively. One of them has had a spinal fusion. In view of the rather striking relief of pain in these patients by removal of the 5th lumbar lamina, spine, inferior articulating facets, and complete decompression of the L5 and S1 nerve roots, I feel that this procedure should be employed in patients suffering symptoms and signs caused by spondylolisthesis. The orthopedic surgeon and neurosurgeon should determine the necessity for lumbosacral fusion. Fusion is not necessarily indicated in all patients. It is especially not indicated in older people or in patients with only a pre-spondylolisthesis.

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THE USE OF CHOLINERGIC BLOCKING AGENTS

IN THE TREATMENT OF CRANIO-CEREBRAL INJURIES

DANIEL RUGE, M.D.

Department of Surgery, Northwestern University Medical School, Chicago, Illinois

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ACETYLCHOLINE is the mediator of preganglionic nerve impulses in both the sympathetic and parasympathetic nervous systems.[6,9] In this respect its action is similar to the effect of nicotine. Hence, the stimulating action of acetylcholine on ganglia has been termed "nicotinic."

Acetylcholine is also liberated at the end organ upon stimulation of the parasympathetic nervous system. The similarity between its action in that location and the effect of muscarine has given rise to the term, "muscarinic." This is in contrast to the release of an epinephrine-like substance at the end organ upon stimulation of the sympathetic nervous system (Fig. 1).

The administration of acetylcholine produces responses which include hypotension, diaphoresis and increased gastro-intestinal motility. They are known as cholinergic responses. Atropine is a cholinergic blocking agent which antagonizes the muscarinic action of acetylcholine.

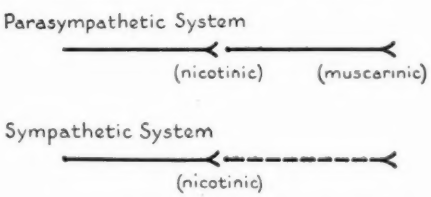

FIG. 1. Acetylcholine is released at the ganglia of both the parasympathetic and sympathetic nervous systems and at the end organ of the parasympathetic system. Its action at the ganglia is called nicotinic, while its postganglionic action is called muscarinic.

Cranio-cerebral injuries frequently produce signs that mimic cholinergic stimulation: hypotension, diaphoresis and occasionally gastro-intestinal motility. Because these phenomena are so similar to the muscarinic action of acetylcholine, it has appeared logical to treat them with anti-muscarinic agents. Ward[15] has reported encouraging results in the treatment of cranio-cerebral injuries by the daily use of large amounts of atropine sulfate (0.1 mg. per kg.).

Acetylcholine normally occurs intracellularly in the brains of mammals. Dikshit[4] demonstrated that extracts prepared from the brains of cats and rabbits have the same pharmacologic actions as acetylcholine. When administered intravenously, a decrease in blood pressure resulted and upon introduction into the ventricles of the brain, respirations were inhibited. The perfused frog heart was also depressed. He found that extracts made from the basal ganglia contained 0.4 gamma per cent of acetylcholine and the

cerebrum and cerebellum contained lesser amounts. Chute, Feldberg and Smyth[3] perfused the cat's head and found that 2 cc. solution of the perfused eserinized blood had the same acetylcholine content as 2 cc. solution of acetylcholine diluted 1–400 million. When the brain was removed and the perfusion repeated no acetylcholine was present.

Acetylcholine is not a constituent of normal cerebrospinal fluid but Tower and McEachern[14] recovered varying quantities of acetylcholine in the cerebrospinal fluid of epileptics and patients who had sustained severe cranio-cerebral injuries. They noted that recovery was associated with a decrease in acetylcholine in the cerebrospinal fluid. Employing contraction of the frog's rectus abdominis muscle for biological assay, Bornstein[1] measured 2.7 to 10.0 gamma of acetylcholine in the cerebrospinal fluid of animals that had received concussive trauma to the head. When the same quantity of acetylcholine was introduced into the cisterna magna of animals, they became quiet and listless but no alterations in blood pressure were noted. Feldberg and Schriever[7] have taken exception to the view that acetylcholine could be recovered from the cerebrospinal fluid unless the animal had been eserinized to prevent the destruction of acetylcholine by cholinesterase. Their experiments indicate that eserine, and eserine in combination with adrenalin, administered intravenously, will produce acetylcholine in the cerebrospinal fluid.

The instillation of acetylcholine into the nervous system has resulted in varying reports. Kremer[10] stated that in man the lumbar intrathecal injection of as much as 500 mg. of acetylcholine gave no response. Suh and his associates[13] injected acetylcholine into the cisterna magna and applied it directly to the floor of the 4th ventricle and reported an increase in blood pressure and augmentation of respiration. Dikshit[5] reported a slight inhibition of respiration and occasional cardiac irregularity when small doses of acetylcholine (0.5 gamma) were introduced intraventricularly in cats. Silver and Morton[12] observed sharp falls in the blood pressure when 2.0 to 4.0 gamma were introduced into the hypothalamic region of cats. Similar injections into the lateral ventricle occasionally produced the same blood-pressure effect together with drowsiness and nausea. Henderson and Wilson[8] observed sweating, nausea, vomiting, peristaltic rushes and altered consciousness in humans who had received 2.5 to 7.5 mg. of acetylcholine intraventricularly.

METHOD

In this study an attempt was made to determine if acetylcholine can be identified in the cerebrospinal fluid following a cranio-cerebral injury and if parasympathetic responses to injury are successfully combated with antimuscarinic agents.

Twenty-three dogs, weighing from 10 to 22 kg., were used as the experimental animals. Anesthesia was obtained by intravenous Nembutal.

Two methods of biological assay[11] were employed. The contraction of the

eserinized leech muscle was used to determine the presence of acetylcholine in the cerebrospinal fluid removed by cisternal aspiration. In two instances, quantitative assays were done to measure the concentration of acetylcholine. The gastro-enterectomized cat's blood pressure was also employed to determine the presence of acetylcholine in cerebrospinal fluid aspirated from the cisterna magna of dogs. Continuous tracings from the carotid artery were recorded. In one instance a quantitative assay was made.

Trauma was inflicted by striking the vertex of the skull with a mallet or by cortical incisions made through a small craniectomy and dural incision. Atropine sulfate and banthine in varying dosages were employed to treat the traumatized animals. Atropine sulfate blocks the muscarinic action of acetylcholine (Fig. 1). Banthine is an autonomic blocking agent that inhibits the neural stimuli at the sites of the parasympathetic and sympathetic ganglia as well as the muscarinic effects.[2]

EXPERIMENTAL DATA

Biological assay employing the eserinized leech muscle to determine presence of acetylcholine was done upon the cerebrospinal fluid obtained by cisternal puncture of 4 of the animals. A cisternal puncture was done prior to subjecting the brain to trauma. Assay of this fluid did not yield a contraction of the leech muscle. Cranio-cerebral injuries were inflicted upon the animals and the fluid was again assayed. In 2 animals, samples taken at 20 and 40 minutes following trauma yielded no contraction of the eserinized leech muscle. The contractions occurred, however, in fluid collected 1 hour after trauma. In the cerebrospinal fluid obtained from one of the animals, the contraction was equal to that resulting from 5.2 gamma of acetylcholine per 100 cc. In another the response was equal to that obtained in a solution containing 6 gamma acetylcholine per 100 cc.

Biological assay using the fall in blood pressure of a cat was used in 7 of the dogs. As with the leech muscle, the cerebrospinal fluid aspirated from the cisterna magna prior to intracranial trauma failed to give an acetylcholine response. However, the cerebrospinal fluid procured 1 hour following a cerebral insult was positive in 5 instances (Fig. 2). In 1 of the 2 who failed to show an acetylcholine response, the cerebrospinal fluid was grossly bloody. Cholinesterase which is normally present in blood may have inactivated any acetylcholine that appeared in the cerebrospinal fluid. The response obtained from one of the samples was equivalent to that resulting from a solution of 40 gamma acetylcholine per 100 cc. After the cat was atropinized, the fluid which had previously been capable of causing a drop in the cat's blood pressure was unable to do so (Fig. 3).

The instillation of 5 to 50 gamma of acetylcholine had no effect upon the blood pressure of the untraumatized, anesthetized dog, whether given into the cisterna magna, the lateral ventricle or brain substance. Four of the dogs had a marked drop in blood pressure when 10 mg. of acetylcholine were injected into the cisterna magna. Ordinarily, this was greater in an animal

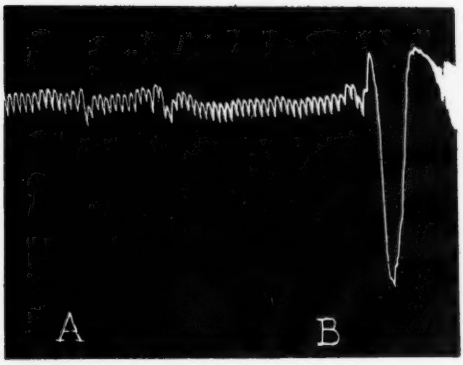

FIG. 2. Assay of cerebrospinal fluid of dog for acetylcholine using the blood pressure of gastroenterectomized cat. (A) Normal cerebrospinal fluid, 2 cc., given intravenously produced no response in blood pressure. (B) The same quantity of cerebrospinal fluid collected 1 hour after cranio-cerebral trauma produced a marked fall in blood pressure.

who had also received cerebral trauma. The administration of 2 mg. of atropine sulfate hastened the return to a normal blood pressure and blocked the muscarinic action of subsequent administration of intrathecal acetylcholine. On several occasions, the same or larger quantities of acetylcholine injected intrathecally into an atropinized animal produced a rise in blood pressure (Fig. 4).

In 1 dog, the administration of 10 mg. of acetylcholine into a lateral ventricle produced the typical parasympathetic blood pressure decline. A prompt recovery occurred when atropine sulfate (0.25 mg.) was given intravenously.

To determine the effect of injecting a substance not containing acetylcholine into the brain, 1 cc. of normal saline was introduced into a cerebral hemisphere. This gave only a slight blood pressure response (Fig. 5A) and was in no way comparable to the marked drop in blood pressure that occurred when 1 cc. of a 1–100 solution of acetylcholine (10 mg.) was injected into a cerebral hemisphere (Fig. 5B). The recovery from intracerebral acetylcholine was prompt when atropine sulfate (1.2 mg.) was given intravenously

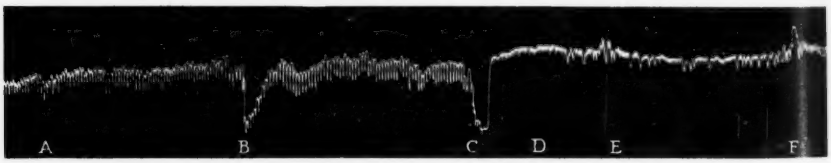

FIG. 3. Assay of cerebrospinal fluid of dog for acetylcholine using the blood pressure of gastroenterectomized cat. All substances were given intravenously. (A) Normal cerebrospinal fluid, 1 cc., had no effect on the blood pressure. (B) 1 cc. cerebrospinal fluid collected 1 hour after cranio-cerebral trauma caused drop in blood pressure. (C) 1 cc. solution of 1:2,500,000 acetylcholine caused a drop in blood pressure similar to B. (D) Atropine, 1 mg. (E) After atropinization, administration of 1 cc. of cerebrospinal fluid obtained 1 hour after trauma gave no acetylcholine response. (F) Acetylcholine, 2 cc. of 1:10,000 solution, produced a slight rise in blood pressure.

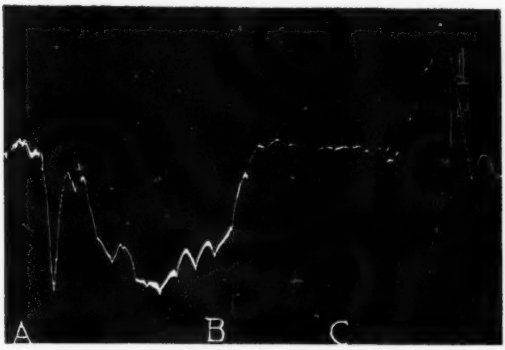

FIG. 4. Blood pressure tracing from carotid artery of dog to show effect of intrathecal administration of acetylcholine. (A) Acetylcholine, 10 mg., introduced into cisterna magna. (B) Atropine, 2 mg. administered intravenously. (C) Acetylcholine, 10 mg., introduced into cisterna magna.

(Fig. 5D). Thereafter, when the same quantity of acetylcholine was injected into the cerebrum, the response was similar to that seen when 1 cc. of normal saline was introduced (Fig. 5E).

To study the effect of a cholinergic blocking agent which also acts at the ganglia of the autonomic nervous system, banthine was used alone and in combination with atropine. After obtaining the drop in blood pressure by intracisternal administration of acetylcholine, 50 mg. of banthine were injected intravenously. In 2 animals no beneficial effects were noted. However, in 1 animal banthine was given in combination with atropine (atropine 0.25 mg. and banthine 10 mg.) and the combined agents brought a prompt recovery in blood pressure and prevented the muscarinic action of acetylcholine when 20 mg. were given intracisternally. Upon premedication with atropine (0.75 mg.) and banthine (30 mg.), the intrathecal injection of acetylcholine (50 mg.) produced the nicotinic response, i.e., a rise in blood pressure.

In an attempt to imitate the muscarinic effects of acetylcholine without

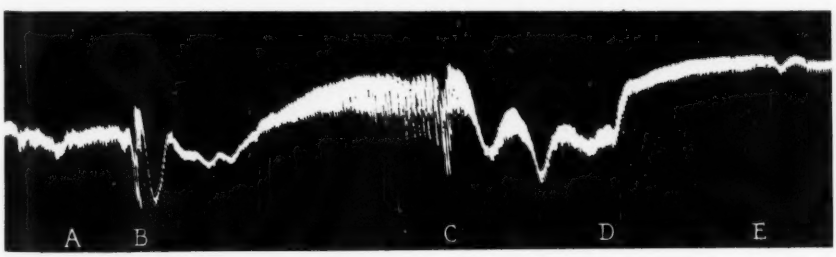

FIG. 5. Blood pressure tracing from carotid artery of dog to show effect of intracerebral administration of acetylcholine. (A) Normal saline, 1 cc., injected into cerebrum had very slight effect upon blood pressure. (B) Acetylcholine, 10 mg. (1 cc. of 1:100 concentration), given intracerebrally produced marked blood pressure drop. (C) Acetylcholine, 20 mg. (2 cc. of 1:100 concentration), given intracerebrally produced greater blood pressure drop. (D) Atropine, 1.2 mg., given intravenously brought prompt rise in blood pressure. (E) Acetylcholine, 10 mg. (1 cc. of 1:100 concentration), given intracerebrally after atropinization produced very slight blood pressure drop.

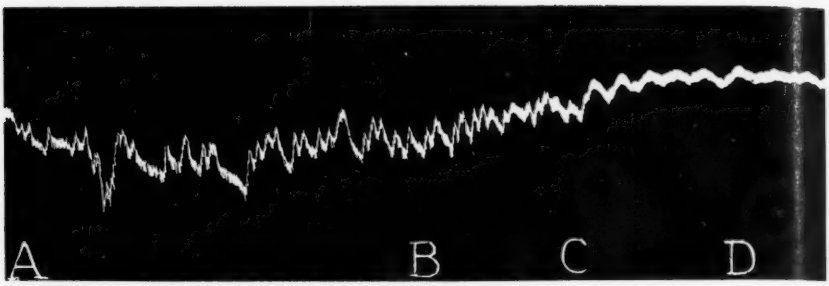

FIG. 6. Blood pressure tracing from carotid artery of dog to show effect of cerebral trauma and response to systemic atropine medication. (A) Cerebral trauma. (B) Atropine, 0.12 mg., administered intravenously. (C) Atropine, 0.12 mg., administered intravenously. (D) Atropine, 0.12 mg., administered intravenously.

introducing acetylcholine, 3 additional animals received concussive trauma or cerebral incisions. In the presence of extensive trauma, cardiac irregularities and decreases in blood pressure appeared. These disappeared promptly upon the administration of relatively small doses of atropine (0.36–0.5 mg.) as shown in Fig. 6. If, however, a considerable subdural hematoma appeared, the drop in blood pressure might be replaced by a hypertensive episode, probably the response to an increased intracranial pressure. The cardiac irregularities resulting from extensive cerebral trauma were lessened by section of the vagus nerves in the neck (Fig. 7B, C). In the same animal 10 mg. of acetylcholine given intracisternally caused no muscarinic effect. However, upon increasing the dosage five-fold, the muscarinic response again appeared and was subsequently blocked by atropine.

DISCUSSION

Many cranio-cerebral injuries produce the symptoms of shock for only a short time. Recovery may promptly result upon the institution of ade-

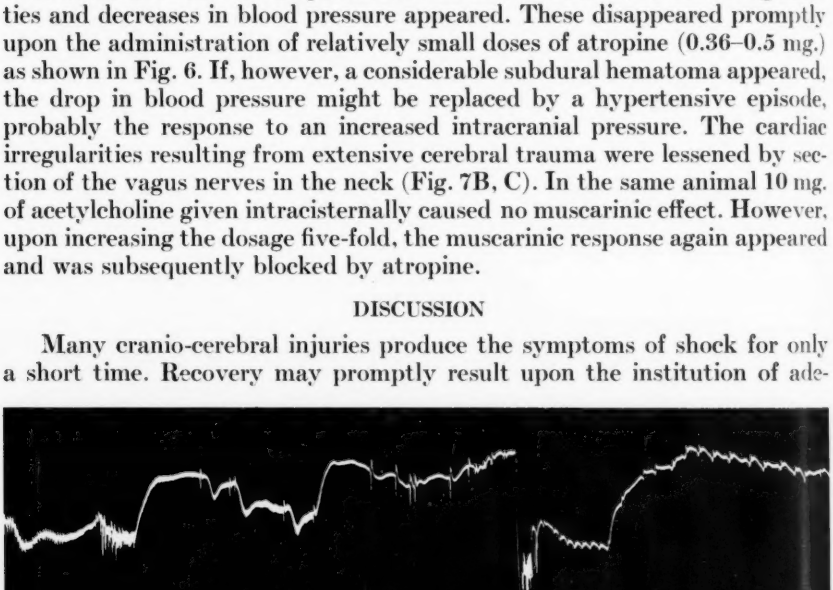

FIG. 7. Blood pressure tracing from carotid artery of dog to show effect of vagotomy, intrathecal acetylcholine and response to atropine. (A) Cerebral trauma produced low blood pressure. (B) Section of right vagus nerve in neck produced temporary rise in blood pressure. (C) Section of left vagus nerve in neck produced more prolonged rise in blood pressure. (D) Acetylcholine, 10 gm., introduced into cisterna magna caused no drop in blood pressure. (E) Acetylcholine, 50 mg., introduced into cisterna magna caused drop in blood pressure. (F) Atropine, 0.6 mg., administered intravenously produced a prompt recovery. (G) Acetylcholine, 50 mg., introduced into cisterna magna did not alter blood pressure after atropinization.

quate nursing care and supportive measures. With the development of increased intracranial pressure as it occurs, for example, if there is an intracranial hematoma, the low blood pressure and rapid pulse are replaced by a gradual rise in systolic blood pressure, increase in pulse pressure and a decrease in cardiac rate. In those patients, treatment is directed toward the removal of the hematoma.

However, many patients who have sustained cerebral insults continue in a state of shock and management often consists of blood transfusions and drugs which stimulate the sympathetic nervous system. Such procedures may have only a transient effect. It appears logical to employ anti-muscarinic agents to combat the signs that simulate a profound parasympathetic discharge.

SUMMARY

Acetylcholine apparently is liberated from traumatized central nervous tissue and some of it diffuses into the cerebrospinal fluid where minute quantities can be measured. When relatively large quantities are introduced into the brain, ventricles or cerebrospinal fluid system, characteristic muscarinic responses of blood pressure are observed. The same responses are not noted when similar amounts of normal saline are injected. Cerebral trauma also produces cardiac irregularities and decreased blood pressure. Cholinergic blocking agents, particularly atropine sulfate, have a beneficial effect upon the parasympathetic responses that accompany cerebral trauma because they block the muscarinic responses of acetylcholine.

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METASTATIC TUMORS OF THE BRAIN FROM A NEUROSURGICAL POINT OF VIEW

A FOLLOW-UP STUDY OF 158 CASES

TORE PATRICK STÖRTEBECKER, M.D.

Neurosurgical Clinic, Serafimerlasarettet, Stockholm, Sweden*

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THE purpose of the present paper is to evaluate the neurosurgical treatment of metastatic tumors of the brain, illustrated by earlier reports from the literature and the material collected from the Neurosurgical Clinic of Serafimerlasarettet.

Frequency of Metastatic Tumors of the Brain. According to Bailey,[2] "statistics indicate that *metastases* to the brain from malignant tumors will be found in about 0.5 per cent of necropsies. The percentage of *primary* neoplasms of the brain is perhaps 1 per cent of all necropsies. This would indicate that of all intracranial neoplasms, both primary and secondary, metastases constitute perhaps 33 per cent. In neurosurgical statistics the percentage of metastatic tumors is only about 4 per cent since usually only those are sent to the surgeon in which the primary source has not been discovered." His impression, however, was that both figures are incorrect.

The frequency of metastasis to the brain, estimated from large general autopsy material, is found to be high, ranging from 13.5 to 37 per cent of the total number of intracranial tumors.[6,16,20,28] On the other hand, in neurosurgical material the same frequency is low, ranging from 3.5 to 7 per cent.[5,7,9]

Cushing[7] stated, with regard to metastatic intracranial tumors: "Their relative scarcity in the series of brain tumours as a whole, viz., 4.2 per cent, by no means represents their true clinical incidence, for we refrain when possible from accepting patients with obvious intracranial metastases since so little can be done for them by surgical procedures."

The neurosurgical treatment of intracranial metastatic tumors is considered by most authors to be a thankless task.[2,8,14] Grant[14] expressed the opinion that "surgery, whether radical or palliative, is of no ultimate benefit to these patients insofar as prolongation of life is concerned."

A more positive neurosurgical approach has been advocated by Oldberg[25] who wrote: "It may be possible to extirpate the metastasis, with great relief to the patient and with prolongation of his life expectancy." This seems to be the fact at least concerning metastatic hypernephroma and I[29] have reported 1 case in which the patient is still alive 17 years after the intracranial operation.

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* Director: Professor Herbert Olivecrona.

"Whether or not to operate when the tumor is known to be of metastatic origin is frequently difficult to decide," to quote Dandy.[8] In the following I shall try to elucidate whether attempts to carry out radical neurosurgical treatment are justified in patients suffering from metastatic tumors of the brain.

MATERIAL

During the 30-year period from 1922 to 1951 a total of 4444 patients with verified brain tumors were admitted to the Neurosurgical Clinic of Serafimerlasarettet. There were 156 cases (3.5 per cent) of metastatic intracranial tumors. A few recent cases from 1952 have been included, thus making the total of 158 cases reported here.

AGE AND SEX INCIDENCE

There is a slight preponderance of males in the youngest group below 20 years and in the ages from 50 to 60. As a whole the sex incidence is about the same in each group.

The youngest patient was a boy of 17 years with a metastasis to the brain from a seminoma. The oldest was a man aged 70 with a cerebellar metastasis from a hypernephroma. In 70 per cent of the cases (114 patients) the age was between 40 and 60 years, the common cancer age.

SITE OF PRIMARY GROWTH

The pathological type of the metastasis and its primary source are important factors in neurosurgery. The primary sites, listed in order of frequency of appearance, are given in Table 1.

Hypernephroma metastases were the most common (20 per cent). Metastases from bronchial carcinoma occurred in 16 per cent and mammary carcinoma in only 7 per cent. These figures, however, are too low, as in about one third (51) of the total number of cases it was impossible to trace the primary growth because most of these patients died at home without autopsy.

According to earlier reports, *bronchial carcinoma* is the most frequent intracranial metastatic type encountered. The following figures have been given: 22 per cent (Elvidge[11]), 25 per cent (Gutting[16]), 29 per cent (Hannemann[17]), 30 per cent (Christensen[5]), 35 per cent (Meagher and Eisenhardt[24]), and 38 per cent (Brunner[4]).

Mammary carcinoma also dominates as a source of intracranial metastatic tumors, according to Christensen,[5] Elvidge[11] (16 per cent), Hannemann[17] (17 per cent), Brunner,[4] Meagher and Eisenhardt[24] (25 per cent), and Gutting[16] (26 per cent).

Hypernephroma as the primary growth is considered rarer; the frequency reported by Elvidge[11] was 3.3 per cent; Hannemann[17] found 4 per cent, Cushing[7] 5.5 per cent, Christensen,[5] Grant,[14] Gutting[16] about 8 per cent, and Davis[9] 10 per cent. The corresponding figure in my material is much higher,

TABLE 1

Primary sites of growth in 158 cases of metastatic tumors of the brain

Cases		Primary Location and Pathological Type	
Total Number	Per Cent		
32	20.2	1) Kidney and suprarenals	Hypernephroma: 30 Adenoca.: 1 Undiff. ca.: 1
25	15.8	2) Lung, bronchi, mediastinum	Squamous epithel. ca.: 2 Adenoca.: 8 Undiff. ca.: 12 Sarcoma: 2 Melanosarcoma: 1
12	7.6	3) Skin	Melanosarcoma: 11 Melanocarcinoma: 1
11	7.0	4) Breast	Adenoca.: 8 Undiff. ca.: 3
15	9.5	5) Gastro-intestinal tract	
3	1.9	a) esophagus	Squamous epithel. ca.: 1 Adenoca.: 2
5	3.2	b) ventricle	Adenoca.: 3 Undiff. ca.: 1 Melanosarcoma: 1
4	2.5	c) colon	Adenoca.: 4
2	1.3	d) rectum	Adenoca.: 2
1	0.6	e) pancreas	Adenoca.: 1
2	1.3	6) Thyroid	Adenoma.: 1 Adenoca.: 1
2	1.3	7) Uterus	Corpus ca.: 1 Cervix ca.: 1
3	1.9	8) Testis	Seminoma: 2 Teratocarcinoma: 1
2	1.3	9) Ovary	Solid carcinoma: 2
1	0.6	10) Skeleton	Osteoid sarcoma: 1
2	1.3	11) Nasopharynx	Squamous epithel. ca.: 1 Undiff. ca.: 1
51	32.3	12) Doubtful source	
43	27.2	a) carcinoma	Undiff. ca.: 16 Adenoca.: 27
8	5.1	b) sarcoma	
158			

as in 20 per cent of all metastatic cerebral lesions the primary growth was a hypernephroma.

The *malignant melanomas*, though they have a great tendency to produce metastases, seem to occur rather infrequently as brain metastases. Christenson[5] reported the frequency as 5 per cent, and in my material it was about 8 per cent.

CASE REPORTS

To illustrate variations in the course of different metastases to the brain some exemplifying cases will be described.

Case 1. No. 928/45. G.W., a 50-year-old man, had suffered from tiredness and headache for about 3 months, and, more recently, from left-sided hemiparesis and hemianopsia to the left.

On examination he showed severe mental confusion and had marked papilledema of 5 to 6 D. Carotid angiography indicated a malignant tumor with pathological

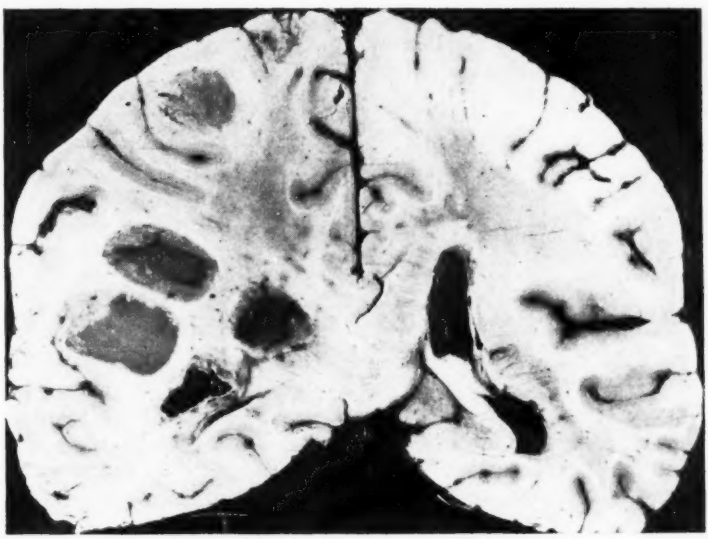

FIG. 1. *Case 1.* Section of brain showing multiple metastatic tumors from a pancreatic adenocarcinoma.

vessels, localized to the right temporal region. The patient was in too poor a condition for operation and died a few days after admission.

Autopsy. There were multiple metastases in the brain from an adenocarcinoma of the pancreas. There were also multiple body metastases (Fig. 1).

Comment. In a case like this all neurosurgical intervention is hopeless.

Case 2. No. 1302/33. F.L., a 51-year-old schoolmaster, had been operated upon for a malignant tumor of the right testis 1 year 8 months prior to his entry. His present illness was of 1½ months' duration with headache, mental confusion, aphasia

and right-sided hemiparesis. He was nearly unconscious on admission and was not operated upon.

Autopsy. There were no signs of local metastatic lesions in the genito-urinary tract, but in the left lung there was a metastasis, the size of a walnut. Section of the brain showed a big central metastatic carcinoma, the size of a goose's egg (Fig. 2).

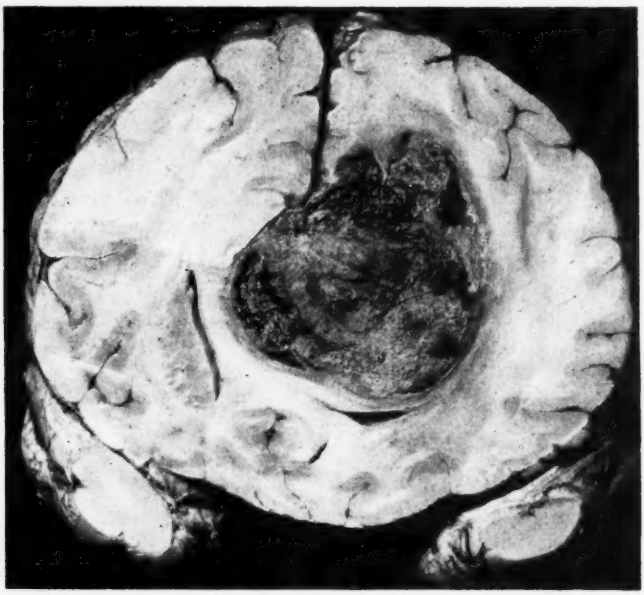

FIG. 2. *Case 2.* Section of brain showing a big central metastasis from a seminoma.

Comment. The absence of local recurrence shows that the metastasis to the lung and brain must have taken place before the ablatio testis, i.e. more than 1 year, 8 months earlier. The central localization in the brain and the large size of the tumor would have made neurosurgical treatment of no value.

Case 3. No. 329/44. S. E., a 44-year-old captain, was operated upon for a malignant tumor of the left testis 2 years prior to entry. His present illness started suddenly 1 month before admission with Jacksonian fits of sensory type localized to the left arm; then epileptic seizures and a left-sided hemiparesis developed. There was no choking of the discs. Carotid angiography showed a right-sided parietal tumor.

At operation the tumor was removed. It was the size of an orange and was sharply separated from the surrounding brain tissue. Microscopically it proved to be a metastasis from a teratocarcinoma.

The patient made a prompt recovery and the hemiparesis subsided. Two months postoperatively headache and left-sided hemiparesis again developed.

Roentgenogram of the chest revealed metastatic lesions and further neurosurgical intervention seemed inadvisable.

Autopsy. There were multiple metastases to the liver, lungs, and vertebral column, and the brain tumor was a very large single metastasis (Fig. 3).

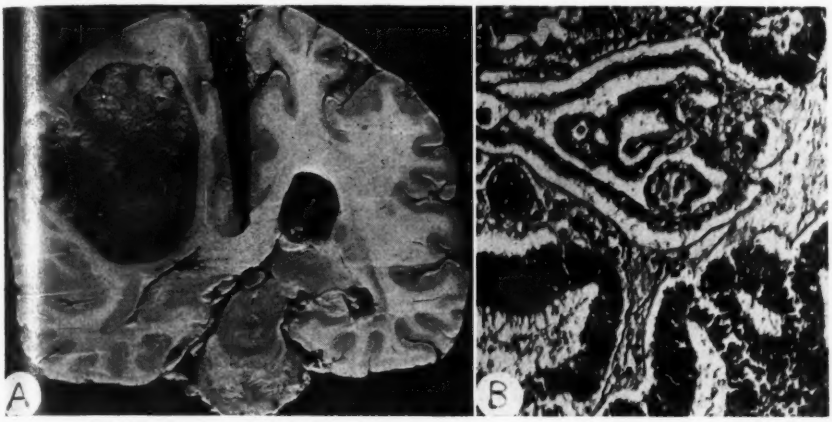

FIG. 3. *Case 3.* (A) Section of brain showing large cystic metastatic tumor from a teratocarcinoma of the testis. (B) Photomicrograph of the metastatic tumor. Hematoxylin-eosin stain, ×130.

Case 4. No. 61/37. H.J., a 51-year-old woman, had had mental confusion, headache, astereognosis and right-sided hemiparesis for 6 months.

There were choked discs of 3 D. Ventriculography pointed to a tumor in the posterior part of the left temporal lobe. Clinically it was considered to be a malignant glioma and X-ray treatment was instituted instead of neurosurgical intervention. The patient gradually wasted and died 1 month after admission.

Autopsy. There was a bronchial carcinoma of the right inferior pulmonary lobe with metastases to the regional lymph glands and to the kidneys. Section of the brain showed a single tumor, the size of half a walnut, in the left parietal region near the cortex. The most striking feature was the marked edema of the brain with dislocation of the ventricular system (Fig. 4).

Comment. Case 4 illustrates the rather common finding of brain edema caused by metastases, as mentioned by Bailey,[2] Davis,[9] Globus and Selinsky,[13] and others.

This series of metastatic tumors contains many unusual findings. In 1951 I[29] reported a case of metastatic hypernephroma in a meningioma. In the following 2 cases the metastases to the brain were from melanosarcomas with very rare sites of growth: 1 was in the lung, and 1 was in the stomach.

Case 5. No. 123/44. J.J., a 49-year-old woman, had a 2 months' history of disturbance of balance, headache and mental confusion.

She was comatose and had left-sided hemiparesis and choked discs of 3 to 4 D. Ventriculography disclosed a right-sided parasagittal lesion.

At operation, a tumor about the size of a walnut and dark, blue-black in color, was enucleated (Fig. 5). Microscopically it was a malignant melanoma.

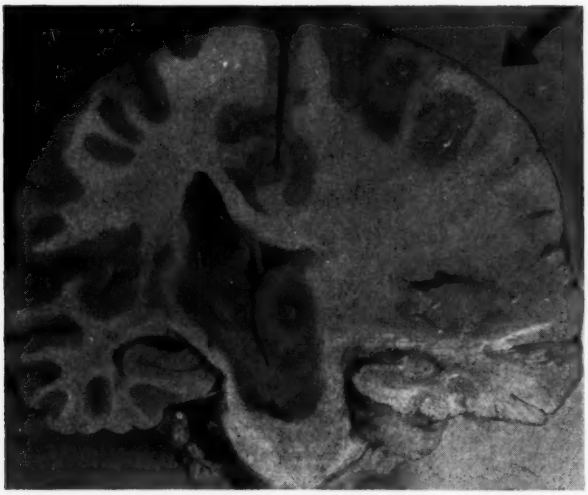

FIG. 4. *Case 4.* Section of brain showing a parietal metastatic tumor (arrow) from a bronchial carcinoma. In spite of the small size of the metastasis there was marked edema with dislocation of ventricular system.

At first the patient made a rapid recovery, but very soon became mentally deteriorated and was transferred to a mental hospital where she died 3½ months after the brain operation.

Autopsy. A careful examination of the skin, scalp, anus and vulva revealed no signs of cutaneous malignant naevi. In the right inferior pulmonary lobe was found an encapsulated tumor, hardly the size of a hazelnut. The color was red-brown to red-blue. All other parts of both lungs were free from any tumors, and the mediastinal lymph glands showed no signs of metastases. There were no signs of metastases elsewhere in the body. Section of the brain disclosed small multiple metastases (one of these, in the left parietal lobe, was the size of a pea, and another, in the right parietal lobe, was dark colored and the size of a hazelnut). There was also a recent encephalomalacia in the left hemisphere, probably the immediate cause of death. The pathologist (Dr. Åke Lindgren) is of the opinion that the melanosarcoma of the lung must, in this case, be considered as the primary growth.

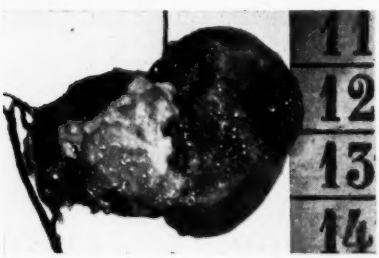

FIG. 5. *Case 5.* Metastatic melanoma removed from parietal lobe. The primary growth was situated in the right lung.

Case 6. No. 800/43. J.G., a 52-year-old farmer, complained of headache and failing vision for 5 months prior to admission.

On examination he showed mental confusion, and had a left-sided hemiparesis. There was markedly reduced vision in the right eye (0.1) and amaurosis in the left. Carotid angiography revealed a large tumor in the right temporal lobe.

Operation disclosed a cystic tumor, the size of a goose's egg, containing a black-brown mass. The temporal lobe with the tumor was partially removed (Fig. 6A) but radical extirpation was impossible since the tumor grew centrally, infiltrating the basal ganglia (Fig. 6B). The patient succumbed 5 days postoperatively.

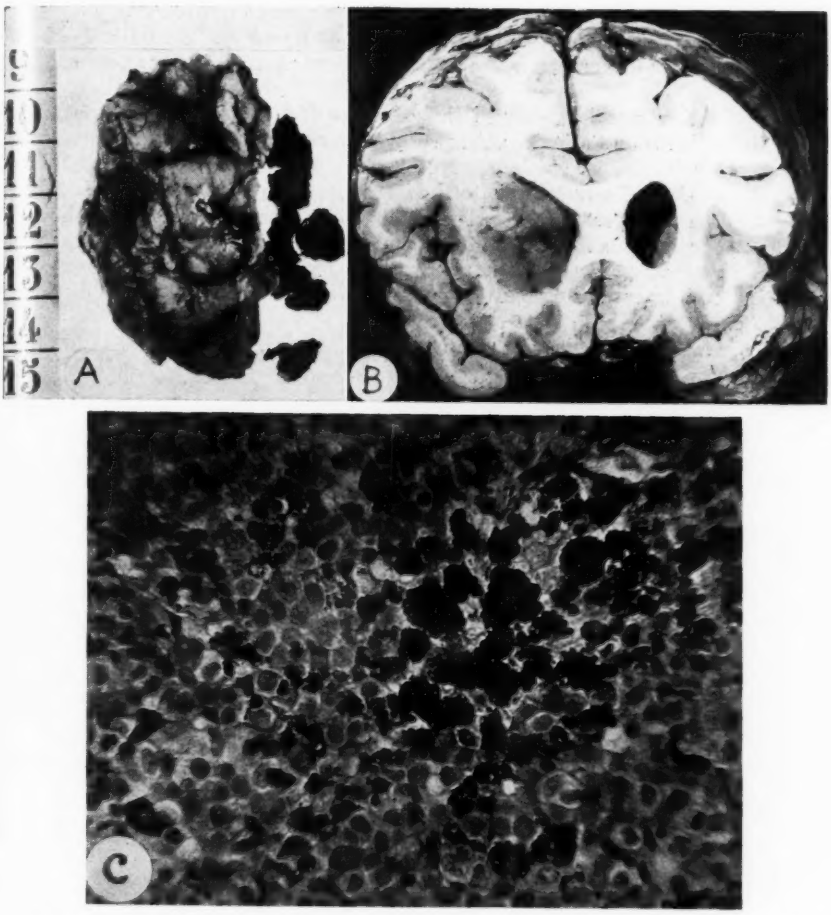

FIG. 6. *Case 6.* (A) Metastatic melanoma removed from right temporal lobe. Site of primary growth was the stomach. (B) Section of brain showing central invasion of metastasis. (C) Photomicrograph of tumor. Hematoxylin-eosin stain, ×360.

Autopsy. There were no cutaneous tumors. In the stomach, on the greater curvature, near the cardia, there was a large malignant melanoma, almost the size of the vola manus. It had infiltrated the submucosa, but had not penetrated the entire ventricular wall. In the mesentery, in the kidneys and suprarenals, and in the endo-

cardium and myocardium were found multiple metastatic lesions, but not in the lungs. Section of the brain showed the central remaining part of the tumor operated upon (Fig. 6B). The pathologist (Dr. Ringertz) is of the opinion that the large tumor of the stomach is the primary one.

Case 7. No. 873/42. M.G., a 47-year-old woman, was admitted with a 6 months' history of headache, nausea and vomiting. About 1 year and 3 months before the onset of intracranial symptoms she had been operated upon for a carcinoma of the left breast.

Examination revealed bilateral choked discs and exaggerated muscle reflexes with ankle clonus on both sides. A few days after entry the patient suddenly died without operative intervention.

Autopsy showed a metastasis to the left lung, but no signs of local metastatic lesions in the breast-scar, or elsewhere in the body. Section of the brain showed a single adenocarcinoma metastasis, the size of a hazelnut, in the left cerebellar hemisphere. There was a large hemorrhage around the metastatic tumor and this bleeding with rise of intracranial pressure apparently was the cause of the sudden death (Fig. 7).

FIG. 7. *Case 7.* Single cerebellar metastatic lesion from a mammary carcinoma. Spontaneous bleeding in the metastatic tumor provoked rise of intracranial pressure and sudden death.

PATHOLOGY

To evaluate neurosurgical treatment for brain metastases, the pathological features characteristic of these tumors must be investigated.

FREQUENCY OF METASTASIS TO THE BRAIN

It is difficult to obtain exact figures on how often different types of tumor produce metastases in the brain.

It is usually stated that *sarcomas* metastasize to the brain more often

than *carcinomas;* according to Rau[26] 68 per cent of all sarcomas, but only 3.2 per cent of the carcinomas metastasized to the intracranial cavity. Krasting[20] found the figures to be 12 per cent for sarcomas and 5 per cent for carcinomas.

Malignant melanomas frequently metastasize to the brain (about 50 per cent of them[2]) and they are thus often met with in neurosurgical material (in about 8 per cent of our own material), even if malignant naevi are rare in a large general autopsy material.

The frequency of metastasis is said to be high for *carcinoma of the lung:* according to Bailey[2] 30 per cent, Gutting[16] 21 per cent and Hannemann[17] about 12 per cent.

Mammary carcinoma is said to metastasize to the brain in 5 to 6 per cent (Bailey,[2] Gutting[16]), though Lenz and Freid[21] found brain metastases in 15 per cent of the primary growths.

The frequency of metastasis of *hypernephroma* to the brain was found by Hannemann[17] to be 8 per cent, by Gutting[16] 10 per cent and by Brunner[4] 16 per cent.

MODE OF METASTASIS TO THE BRAIN

There are several methods of metastasis to the intracranial cavity.

(A) The most common is generally accepted to be via the *blood stream*, as there are no lymphatics in the central nervous system. This first type is, according to Grant,[14] "the single or diffusely scattered discrete nodular lesion more frequently subcortical and apparently only involving the surface of the brain by increase in size and extension of growth. It is evident that these metastases must be blood-borne and embolic in origin from the primary growth."

(B) Another much rarer mode of metastasis is via the *subarachnoid space* in the thoracic or lumbar region and by the *spinal fluid* to the brain (carcinomatosis or sarcomatosis of the meninges.[14,18,19] In these cases we usually find a carpet-like infiltration spread over the bottom of the middle and posterior cranial fossae, involving the cranial nerves, but the brain tissue itself may be totally free from cancer elements. In my material this condition was found in only 7 cases.

(C) Batson[3] proposed that metastases may reach the brain by way of the *vertebral vein complex;* Bailey[2] considered this theory to be illogical. Recent studies by Anderson,[1] however, are considered further supportive evidence of possible routes for spread of metastases via the vertebral venous system from distant primary foci to the cerebrum.

(D) *Direct spread* from adjacent malignant lesions, e.g. from tumors of nasopharynx, may involve the brain.[30] In the present material there were 2 cases in which carcinoma spread from the nasopharynx, with hemianopsia and cerebral symptoms.

INTRACRANIAL LOCALIZATION OF METASTASES

Metastatic intracranial tumors may involve the skull, or the external or internal surface of the dura mater, may lodge in the dural sinuses, may

spread more or less diffusely through the subarachnoid system, or may be localized in the substance of the brain. Metastases to the brain are found to lodge predominantly in the cerebrum since the most direct arterial route to the intracranial space is by way of the internal carotids.[6] The amount of blood passing through the cerebrum is relatively greater than that through the cerebellum.[14]

In my material this opinion is well confirmed, as supratentorial metastases were found in 78 per cent of the lesions. Christensen,[5] too, reported that about 80 per cent of the metastases were supratentorial. She found that they were distributed evenly in all regions of the brain, affecting mostly the cortex.

With regard to a *specific tendency to localization* in the brain, Courville[6] pointed to the parieto-occipital region, probably the result of lodgement of the original embolus of tumor cells in the terminal branches of the middle cerebral artery. He observed that half of the tumors clinically diagnosed as occipital proved to be metastatic. The dominance of the occipital lobe was also pointed out by Brunner.[4]

This is contrary to the findings in my material, in which the majority of the metastatic lesions (70 per cent) were situated in the frontal, temporal and parietal lobes. Only about 5 per cent were occipital.

According to McLean,[23] metastases occur most often to the left cerebral hemisphere; Brunner[4] reported 65 per cent and Krasting[20] 58 per cent. In my material the incidence was about equal in both hemispheres, with a slight preponderance to the right hemisphere.

CLINICAL FEATURES

The symptoms of metastatic cerebral tumors do not differ essentially from those of primary cerebral tumors, but Bailey[2] mentioned "as more or less characteristic simply the intensity of the headache and of the mental confusion, which are out of proportion to the intracranial tension." Globus and Selinsky[12] pointed out that the onset of cerebral manifestations is acute and often precipitate.

I should like to call attention to some initial and early dominating symptoms in my material (Table 2).

As will be seen, *headache* was the most common first symptom, found in 44 per cent of all cases.

The next most frequent initial symptom was *Jacksonian epileptic fits*, found in about 18 per cent of the cases (of motor type in 21, and of sensory type in 7). In 2 cases of metastatic hypernephroma the patients had had a history of Jacksonian fits for 4–5 years before intracranial operation. Foerster[12] described a similar case of 8 years' illness with Jacksonian fits. Jacksonian fits also dominated as an early symptom in 17 other cases, thus having occurred in nearly 30 per cent. The sudden onset of Jacksonian fits may very well be explained by a metastatic embolus in the frontoparietal region (this was the localization in half of all cases).

TABLE 2

Incidence of initial symptoms in 158 cases

	First Symptom %	Early Symptom %	Total %
1. Headache	43.7	44.3	88.0
2. Jacksonian epilepsy	17.7	10.8	28.5
3. Hemiparesis	8.2	26.6	34.8
4. Mental confusion	7.6	29.1	36.7
5. Vertigo	7.6	16.4	24.0
6. Failing vision (of a high degree)	5.1	22.2	27.3
7. Aphasia	5.1	12.0	17.1
8. Epilepsy (not Jacksonian)	4.4	7.0	11.4
9. Vomiting	0.6	21.4	22.2

Hemiparesis was also an important symptom (8.2 per cent). *Mental confusion* was the initial symptom in 7.6 per cent, but occurred as an early symptom in 29 per cent—a total of 36 per cent. *Aphasia* was the initial symptom in 5 per cent. Remarkable also is the markedly *impaired vision* as an early symptom (27 per cent). In several cases the patient became amaurotic (see below concerning choked discs).

NEUROLOGICAL EXAMINATION AND DIAGNOSTIC CRITERIA

Choked discs were characteristic findings of high frequency. In only 18 per cent of the cases were the eyegrounds normal. Moderate papillary stasis was found in 28 per cent and highly choked discs, 4–5 diopters and more, with severe eyeground damage, edema and perivascular hemorrhage, occurred in about half of the cases (48 per cent). That even a small tumor may give rise to brain edema and highly increased intracranial pressure was often found; a typical autopsy finding is shown in Fig. 4 (Case 4).

The *cerebrospinal fluid* showed changes in 10 cases only; in 5 there was a pathologic increase in albumin; in 3 a pleocytosis, and in 2 a positive colloidal curve. These changes were found in the cases of diffuse carcinomatosis of the meninges and melanosarcoma. In the other cases the fluid was quite normal.

The *sedimentation rate* (SR) in my material (132 cases examined) was as follows, calculated in mm. in 1 hour:

	Sedimentation Rate (mm./1 hr.)								
	10	10–19	20–29	30–39	40–49	50–59	60–79	80–99	>100
in per cent of cases	29	29	10	9	9	5	6	2.3	0.7

A considerably increased sedimentation rate is sometimes a sign of malignancy, and may be an aid in diagnosis and prognosis. In about 40 per cent of the cases examined the SR was more than 20 mm./hour. In patients with

lung carcinoma the SR was rather high—above 30 mm./hour in 12 out of 23 cases. The patients with markedly increased sedimentation rate (14 per cent above 50 mm. in 1 hour) and especially those with extremely high SR up to above 80 (4 cases) all had multiple metastases; the highest value was 120 mm./hour in a case of metastatic sarcoma.

On the other hand, it is remarkable that many patients with malignant metastatic lesions of the brain have a normal sedimentation rate, below 10 mm. in 1 hour. In the present series nearly 30 per cent had a normal SR.

It is difficult to draw any definite conclusions regarding the relationship of sedimentation rate to the type and extent of metastases. A markedly increased sedimentation rate is suggestive of malignancy, but a low sedimentation rate does not rule against it. In 2 cases in which there were both lung and brain metastases the SR was only 4 mm./hour.

X-RAY EXAMINATION OF THE LUNGS

This was performed in 74 cases. In 29 of these there were positive findings: in 13 carcinoma of the lung, and in 16 metastases to the lungs. Thus in nearly 40 per cent of the cases examined the pulmonary roentgenograms were suggestive of malignancy.

Bailey[2] is of the opinion that any patient in middle age or older with sudden development of a psychosis or focal cerebral symptoms, not obviously luetic or vascular in origin, should have a roentgenogram made of his lungs. Davis[9] also emphasized the importance of roentgenograms of the lungs.

The diagnosis of primary or metastatic pulmonary lesions may be of great value in many cases, and save much futile operating, according to Bailey.[2] However, I want to point out that patients may live free from symptoms for a rather long period with pulmonary metastases. One of my patients with pulmonary and brain metastases from a hypernephroma survived 10 months after the findings were observed in the roentgenogram, and the following patient survived for more than 3 years.

Case 8. No. 793/44. N.K., a 51-year-old captain, who about 4 years previously had been operated upon for a thyroid adenoma, had bitemporal hemianopsia. Roentgenograms showed destruction of the sella, and pneumoencephalography disclosed a suprasellar tumor.

Operation revealed a capsulated tumor from the pituitary region expanding forward between the optic nerves. The tumor was partially removed intracapsularly by suction. On microscopic examination it was found to be an adenomatous tumor of thyroid origin (Fig. 8 A, B). X-ray of the lungs showed a metastasis on the right side. The sedimentation rate was 4 mm./hour.

The postoperative course was uneventful, and the patient lived for more than 3 years after the roentgenologic diagnosis of pulmonary metastasis.

These 2 cases illustrate the value of radical neurosurgery even when there are pulmonary metastases, especially if the metastases are of a more benign type, such as from hypernephroma or thyroid adenoma.

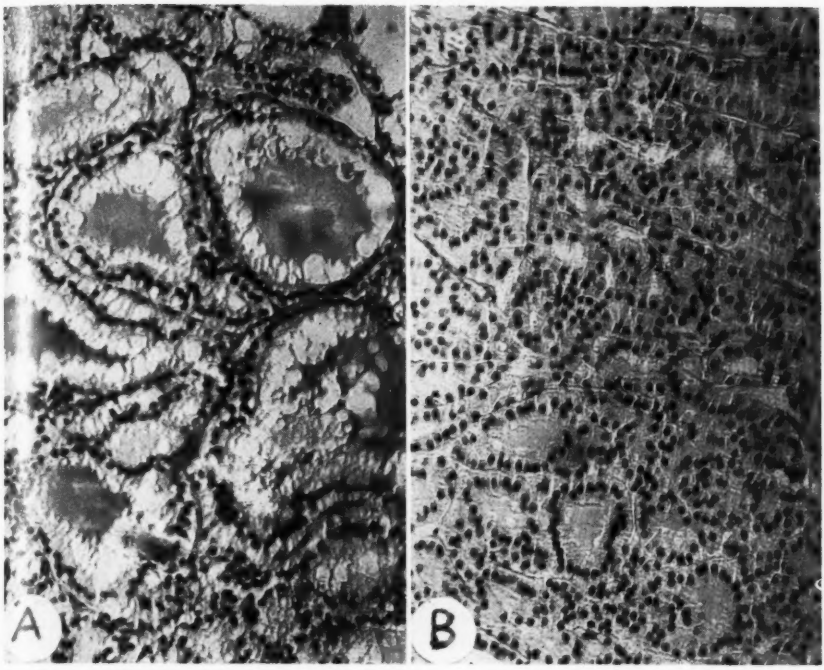

FIG. 8. *Case 8.* Photomicrographs of (A) metastasis from thyroid to pituitary region, and (B) primary thyroid growth removed 4 years before the brain operation. Hematoxylin-eosin stain, ×180.

DIAGNOSIS OF INTRACRANIAL TUMORS BY ROENTGENOLOGY

In 32 cases (about 20 per cent) roentgenograms of the cranium showed pathologic changes such as signs of increased intracranial pressure by destruction of the sella or a shift of a calcified pineal body. The localization of the intracranial tumor was made by means of carotid angiography in 45 of the cases and by encephalography or ventriculography in the remaining cases.

NEUROSURGICAL TREATMENT AND OPERATIVE FINDINGS

Of our 158 patients with intracranial metastasis, 125 were operated upon.

With regard to neurosurgery of brain metastasis several factors must be taken into account. (1) The size of the tumor, but as has already been pointed out even a small tumor may cause tremendous edema (Fig. 4); (2) the type of tumor, whether it is solitary or multiple; (3) and more important, is the growth of the tumor, whether it is infiltrating into the surrounding brain tissue or whether it is separate and encapsulated, and thus easily enucleable.

The size of intracranial metastatic tumors was found to be as follows:

	Size of Tumor						
	Less than a Hazelnut	Hazel-nut	Walnut	Hen's Egg	Goose's Egg	Orange	"Carp-like"
In per cent of the lesions	6	14	31	26	11	6	6

More than half of the metastatic lesions varied in size from a walnut to a hen's egg; however about 20 per cent were only the size of a hazelnut or less. This is interesting to note and might be of importance with regard to the operability.

SINGLE OR MULTIPLE BRAIN METASTASES

Cushing[7] stated, "Ordinarily metastases to the brain are multiple. . . . Nevertheless one may occasionally encounter what appear to be solitary tumours sometimes of comparatively large size."

(A) In the present material, at *intracranial operation* 94 tumors were found to be easily enucleable. They were frequently situated just below the surface of the brain and were removed often with the finger, without much bleeding (Fig. 9). These metastatic lesions seemed macroscopically to be

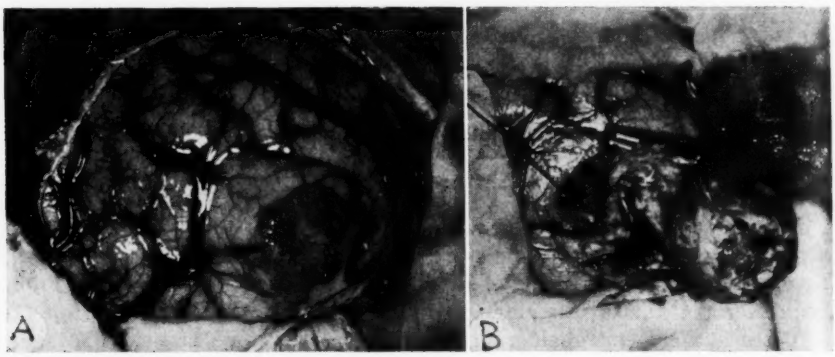

FIG. 9. Operation for brain metastasis from an adenocarcinoma. (A) Tumor is on cortical surface, sharply demarcated from surrounding brain tissue. (B) Enucleation of tumor.

separate from the brain tissue, an observation which was often verified at autopsy, with no microscopic evidence of cancer elements at the site of operation. In only 22 cases was the surgically exposed tumor of a more infiltrating type; these included 7 cases of carcinomatosis or sarcomatosis of the meninges.

With regard to the *multiplicity* of metastases to the brain it is difficult to judge from the operative findings; but by means of modern X-ray examination, angiography and pneumoencephalography, correlated with the clinical picture and neurological findings, there is a high degree of accuracy in

localizing the metastases. At the time of brain operation the tumor seemed to be solitary in 67 cases; and multiplicity was found in 15 cases (not including the 7 cases of carcinomatosis of the meninges). In the remaining cases it was difficult to judge.

(B) *Postmortem examination.* A total necropsy was performed in 105 cases and a brain section was made in 112 cases. The remainder were not examined, as many of the patients died at home. The frequency of a single metastasis to the brain was revealed to be less than half of that found at time of brain operation; thus in 39 of the necropsies a single metastatic lesion of the brain was found. Only in 20 autopsies were there no signs of metastases elsewhere in the body. Thus the majority (about two thirds) of the patients showed a multiplicity of metastases, but with regard to the metastases of the brain more than one third were single ones. Krasting's[20] autopsy findings were more favorable, as the brain metastasis was a solitary one in two thirds of the cases.

OPERATIVE MORTALITY

Of the 158 patients reported, 125 were operated upon, with 31 fatalities within 20 days of operation, making a 24.8 per cent operative mortality.

This rather high operative mortality in spite of neurosurgical procedures that were often easy, must be viewed in relation to the fact that many of the patients were in a poor condition on admission to the clinic. In earlier reports the operative mortality in cases of brain metastasis also seems to be rather high; Eisenhardt[10] found 20.9 per cent and Cushing[7] 22.5 per cent.

With regard to the 33 patients not operated upon there were various reasons for deciding against neurosurgical intervention. The patient was either in too poor a condition, or the diagnosis of a metastatic lesion was suspected in view of a history of previous removal of a malignant tumor. Also, in some of these cases the roentgenograms of the lungs showed signs of pulmonary metastases. On admission these 33 patients were perhaps in a poorer physical condition than the 125 patients on whom intracranial operation was performed.

It is permissible, however, to compare these two different groups with regard to the survival periods after onset of intracranial symptoms (Table 3).

LATENT PERIOD OF BRAIN METASTASIS

In some cases a long interval had elapsed between removal of the primary body growth and the onset of cerebral symptoms. In Gutmann's[15] case the brain showed metastases 18 years after an operation for ovarian tumor.

In my material there are 24 cases (about $\frac{1}{5}$ of the brain operations) in which the primary body growth had been removed before the brain operation for a metastatic tumor. The long latency to onset of intracranial symptoms is remarkable—in 13 cases more than 3 years, and in 21 cases 1 year or more.

Christensen[5] reported the case of a man who 9 years earlier had had a

TABLE 3

*Survival period after onset of intracranial symptoms in 158 cases of intracranial metastatic tumors**

Survival Period in Years	Cases			Hypernephroma	Bronchial Carcinoma	Malignant Melanoma	Mammary Carcinoma	G-I Tract Carcinoma	Thyroid	Uterus	Mixed Group Testis, Ovary, Renal Carcinoma, Osteoid and Lung Sarcoma, Carcinoma Nasopharynx	Doubtful Primary Source	
	Total Number	Intracranial Tumor Operation	No Brain Operation									Carcinoma	Sarcoma
<¼ yr.	20	6	(14)	1+(3)	1+(1)	1+(2)	(2)	1+(2)	(1)		1+(1)	1+(2)	
¼– ½ yr.	43	33	(10)	3	8+(3)	5	1	5+(1)		(1)	4+(1)	5+(4)	2
½– 1 yr.	42	36	(6)	9	6+(3)	(1)	1+(2)	2		1	2	10	5
1– 2 yrs.	33	30	(3)	3		4	5	4			(1)	13+(2)	1
2– 3 yrs.	8	8		3		1			1		1	3	
3– 4 yrs.	6	6		4								1	
4– 5 yrs.	3	3		2								1	
5–10 yrs.	2	2		1								1	
10–15 yrs.													
>15 yrs.	1	1		1									
Total	158	125	(33)	27+(3) 30	15+(7) 22	11+(3) 14	7+(4) 11	12+(3) 15	1+(1) 2	1+(1) 2	8+(3) 11	35+(8) 43	8
Average survival period in months	15.4	18.2	5.5	26.4	6.6	9.2	11.4	8.2	22.0	6.8	8.4	15.8	9.0

* In 125 cases the intracranial tumor was operated upon. In 33 cases no operation for brain metastasis was performed (figures in parentheses).

nephrectomy performed for *hypernephroma*. He was operated upon for an intracranial tumor, which microscopically proved to be a metastatic hypernephroma. Three years after the brain operation the patient was still alive and back at full time work. The survival period after removal of the primary body growth was thus more than 12 years.

The metastasis of malignant *melanoma* often makes its first appearance long after the original growth has been removed. In 3 cases the latent period was 8, 4 and 4 years respectively. In 2 other cases of malignant melanoma, in which the cerebral metastatic lesion was not operated upon, the period from extirpation of the malignant naevus to onset of intracranial symptoms was 6 and 5 years respectively.

With regard to metastasis to the brain from *mammary carcinoma*, there may also be a long latency (10 years in 1 case). Meagher and Eisenhardt[24] reported a case in which the onset of intracranial signs occurred 12 years after a primary lesion in the breast had been removed.

In 3 of my cases in which the secondary cerebral tumor was not extirpated the latent period was 5 years in 1 case and about $1\frac{1}{2}$ years in the other 2. In another female, aged 39 years, with mammary carcinoma, the latency was only 1 year and 4 months. The metastatic lesions in this case were multiple, some involving the cerebellar hemisphere, a site that will give rise to earlier onset of clinical symptoms from increased intracranial pressure.

The following case shows a long latent period of metastasis from a *sarcoma*.

Case 9. No. 559/37. A.P., a 23-year-old female, about 10 years prior to admission was operated upon for a giant cell sarcoma, the size of an orange, situated in the right gluteal region. Three years later there was a local recurrence with pararectal extension; the tumor was extirpated with rectal amputation and formation of a preternatural anus. Subsequently she was symptom free for about 7 years. Then headache, vomiting and disturbed vision occurred.

Examination 3 months after onset of intracranial symptoms revealed choked discs of 4 D with peripapillary hemorrhages and exudate. Ventriculography showed signs of multiple brain tumors.

At operation a tumor, the size of a walnut, was easily enucleated from the right temporal lobe.

The patient gradually wasted and died 12 days after intracranial operation.

Autopsy showed another large tumor in the left temporal lobe (Fig. 10 A) and there were several metastases in the body. Histological diagnosis: metastatic sarcoma of the brain (Fig. 10B).

In a case of *colon carcinoma* there was a latency of $4\frac{1}{2}$ years after removal of the primary growth. At the time of the primary operation there were metastases to the regional lymph glands of the mesocolon. The cerebral metastatic lesion was situated in the right frontal lobe; at operation it was the size of a hen's egg and weighed 35 grams. The long latent period in this case might be attributable to the fact that the metastatic tumor was situated in the frontal lobe, which is a comparatively silent zone.

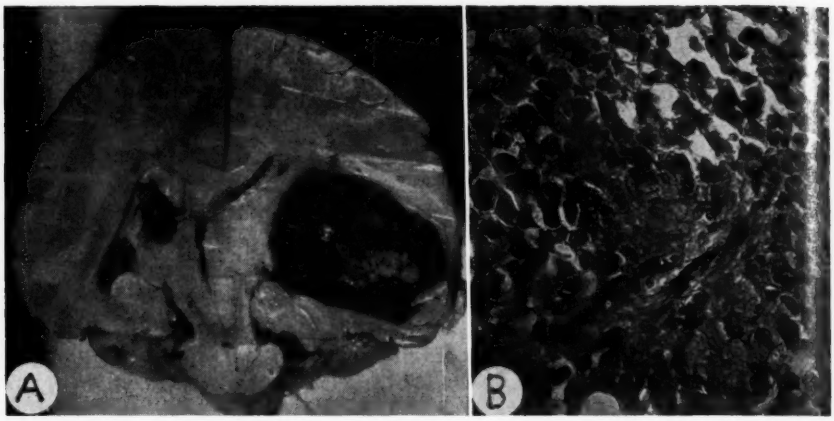

FIG. 10. *Case 9.* (A) Coronal section of brain showing a metastatic lesion from a sarcoma removed 10 years previously from the right hip. (B) Photomicrograph of metastatic tumor. Weigert-van Gieson stain, ×280.

Comment. Those cases in which the primary body tumor had been previously removed and there were no signs of local recurrence are of both theoretical and practical interest with regard to the long latent period before onset of intracranial symptoms. The metastasis to the brain, which must have taken place before the primary growth was operatively removed, apparently remained dormant for several years.

If the interval between metastasis and production of cerebral symptoms may be so long (up to 10 years or more), some of these tumors might have a fairly good prognosis. Moreover, if they are single, neurosurgical intervention might result in a cure (1 of our patients with hypernephroma is still alive 17 years postoperatively[29]).

According to Cushing,[7] in cases with a long latency to onset of cerebral symptoms, we may question if the symptoms are caused by a primary brain tumor and not by a metastatic lesion. Meagher and Eisenhardt,[24] and Oldberg[25] described cases in which a primary body growth had been removed, and in which at intracranial operation the suspected brain metastasis proved to be a meningioma.

SURVIVAL PERIODS

The common point of view with regard to the neurosurgical treatment of brain metastases seems to be a pessimistic one. The postoperative survival was found to be a few months only by Grant,[14] Meagher and Eisenhardt,[24] Dandy,[8] Bailey,[2] and Elvidge and Baldwin.[11]

Davis[9] stated, "Though one may quite frequently afford relief from severe headaches by operation to patients with metastatic tumors, the survival period in our group has averaged less than two months following operation."

Meagher and Eisenhardt[24] concluded, with regard to intracranial metastases from the breast, "The course from the appearance of intracranial symptoms is rapid, fatality ensuing on an average of six months, and operative interference is survived on an average of six weeks, the longest period being five months."

Single cases of brain metastasis with unexpectedly long postoperative survival periods have been published. Cushing[7] reported a postoperative survival of 6, 3 and 2 years respectively. Oldberg[25] found a survival period of 3 and 2 years after removal of intracranial metastasis from lung and breast carcinomas respectively. Christensen[5] reported a patient with metastatic hypernephroma of the brain who was working full time 3 years postoperatively.

To evaluate neurosurgical treatment of brain metastasis in our own material, the following studies have been made.

(a) The survival periods *after onset of intracranial symptoms* have been compared in different groups, with and without neurosurgical interference (Figs. 11 and 12).

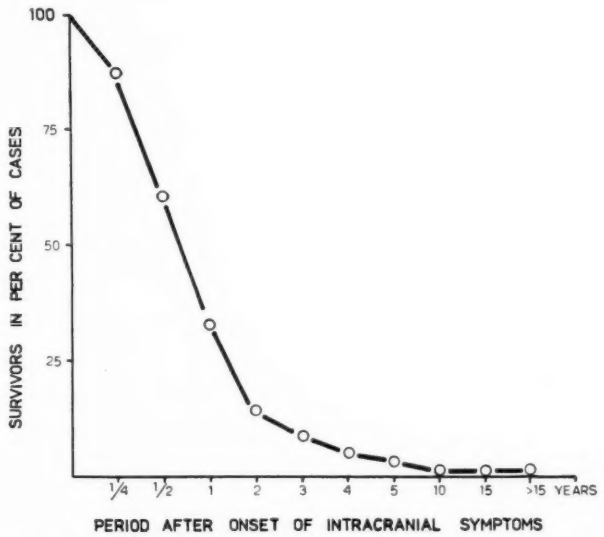

FIG. 11. Incidence of survivors at varying periods after onset of intracranial symptoms in 158 cases of intracranial metastatic tumors.

(b) The survival periods *following brain operation* have been measured (Fig. 13), with special reference to the postoperative condition and capacity for work.

In Table 3 the survival periods after onset of intracranial symptoms are given for 158 cases of brain metastases.

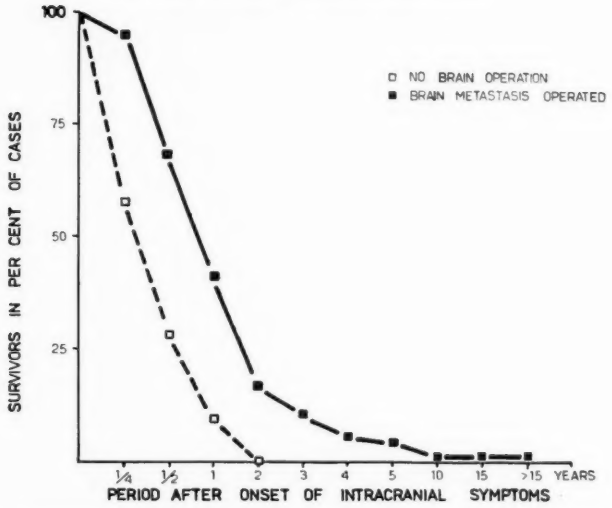

FIG. 12. Incidence of survivors: 125 patients neurosurgically treated are compared with 33 untreated ones (correlated in per cent).

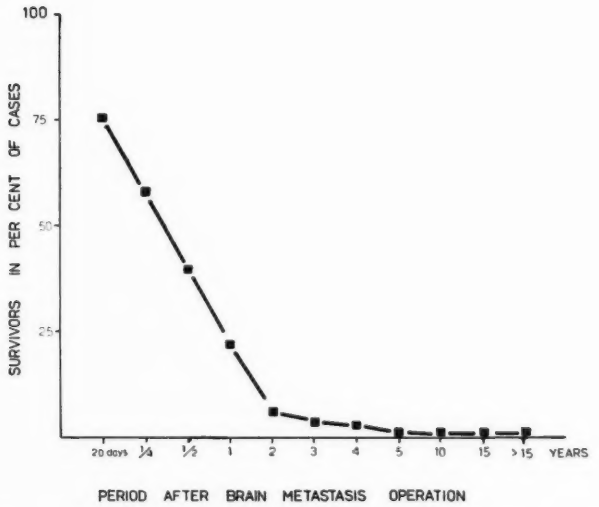

FIG. 13. Incidence of survivors after intracranial operation among 125 cases of neurosurgically treated brain metastasis.

TABLE 4

Survival period after intracranial operation on metastatic tumor in 125 cases

Survival Period in Years	Cases Total Number	Hypernephroma	Bronchial Carcinoma	Malignant Melanoma	Mammary Carcinoma	G-I Tract Carcinoma	Thyroid Carcinoma	Uterus Carcinoma	Mixed Group Testes, Ovary, Renal Carcinoma, Osteoid, Lung Sarcoma, Ca. Nasopharynx	Doubtful Primary Source	
										Carcinoma	Sarcoma
<20 days	31	5	7	2	2	2			4	6	3
20 days–¼ yr.	22	4	4	4	1	5			2	2	
¼– ½ yr.	22	2	2	2		2			1	9	4
½– 1 yr.	23	7	2	3	3	1		1		6	
1– 2 yrs.	20	5			1	2			1	10	1
2– 3 yrs.	3	2								1	
3– 4 yrs.	1						1				
4– 5 yrs.	1	1									
5–10 yrs.	1									1	
10–15 yrs.											
>15 yrs.	1	1									
Total number of cases	125	27	15	11	7	12	1	1	8	35	8
Average survival period in months	10.5	17.2	2.6	4.0	7.0	4.6	42.0	9.0	3.6	11.5	4.7

The survival period is a measure of the degree of malignancy of various tumors. Thus in the group of hypernephromas the survival period is longer than that of the other types of tumor. The average survival period for all 158 cases is 15.4 months, for hypernephromas 26.4 months, and for bronchial carcinomas 6.6 months, which is the shortest average survival period among the major groups of intracranial metastatic lesions.

If the group of 33 nonoperated cases (Table 3) is compared with the group of 125 cases in which operation was performed, it will be seen that the average survival after onset of intracranial symptoms was 18.2 months in the group of neurosurgically treated, and 5.5 months in the non-treated cases.

The survival periods after intracranial operation in 125 cases of brain metastases are given in Table 4. The average survival for the whole material was 10.5 months. It was highest in the group of hypernephromas, 17.2 months, and considerably lower in the other groups (except for a single case of thyroid carcinoma).

These postoperative survival periods and the percentage of survivors seem to be much higher than any previously published. It may be of interest to compare them with those in cases of glioblastoma multiforme. Ringertz[27] found the average postoperative survival of patients with cerebral glioblastomas to be 11 months and the postoperative 3-year survival rate to be 2.9 per cent. The corresponding figures in my material are about the same, 10.5 months and 3.2 per cent. Thus in any case it may not be more hopeless to operate upon a brain metastasis than upon a glioblastoma.

On the contrary, if the primary body growth has been removed before the operation for brain metastasis, the results of neurosurgical intervention in some cases may be good.

PREVIOUS REMOVAL OF PRIMARY BODY GROWTH

In the present material there were 24 cases of brain metastasis in which the primary body growth had been removed previously. It may be of great interest to estimate whether neurosurgical treatment in such cases is more favorable than when the primary body tumor is still present at the time of the brain operation.

In this group of 24 cases, the average survival period after brain operation was 17 months, and after onset of intracranial symptoms it was 22 months.

The corresponding figures in the other group (101 cases), in which the primary body growth was still present, were 7.8 months and 15 months respectively.

With regard to prolongation of life, it would seem that the first group is more favorable, and if we consider the individual cases in our own material we must admit some benefit from removal of the primary growth before the intracranial operation. The metastasis to the brain might be a single one and the risk of development of new metastases is eliminated, since the pri

mary growth has already been extirpated. Of course, metastases that have already occurred may still be latent in the brain.

POSTOPERATIVE CONDITION

With regard to the general health of the patients after the brain operation, there is often at least a temporary improvement.

Many patients obtain relief from the very troublesome headache, a fact already pointed out by others.[9,14] Some patients show a surprising improvement in general health, and in a few instances they have returned to active life. In previously reported cases[5,7,25] some patients have been symptom free and led a normal active life for several years (5 years in one of Cushing's cases[7]).

In the present material 19 patients, out of 125 operated upon, went back to work at least for a short time, 10 patients up to half a year or less, 5 for about 1 year, 2 for 2 years and 2 for more than 5 years. One patient with a metastatic hypernephroma was alive 17 years postoperatively in tolerably good health, with slight ataxia and impaired vision, but able to do light manual work, read papers and write letters.

Unfortunately there is often a diminution of vision caused by choked discs. In some cases there is even a total amaurosis, e.g. in 1 patient with a postoperative lifetime of more than 4 years who was quite well otherwise.

A patient with metastatic tumor, reported by Cushing,[7] had global aphasia before operation, but afterwards he remained symptom free and led his usual active life for 5 years. Further to quote Cushing,[7] "the fact that . . . patients . . . have had unexpectedly long postoperative survival periods . . . after the removal of a metastatic carcinoma brings a certain gleam of hope to what surgically is an otherwise most gloomy subject."

HYPOPHYSECTOMY IN TREATMENT OF METASTASES

Luft and Olivecrona[22] reported 25 cases of hypophysectomy as a therapeutic measure for malignant tumors. According to these authors carcinomas of the breast and possibly also of the prostate, as well as chorionic epitheliomas in a stage when other methods of treatment are no longer effective, offer a promising field for hypophysectomy.

In the following 2 cases in our series of metastatic tumors of the brain, the intracranial lesion was extirpated and later a hypophysectomy was performed.

Case 11. No. 705/52. E.P., a 43-year-old woman, had been operated upon for a mammary carcinoma 7 months before admission. About 3 months after removal of the breast headache developed, followed by vertigo, vomiting and mental dullness. She had been confined to bed the last month.

Neurological findings were slow cerebration, slight papilledema and nystagmus. Ventriculography showed a tumor in the right cerebellar hemipshere.

At operation a metastatic tumor, half the size of a hen's egg, was easily enucleated.

About 1 month later a total hypophysectomy was done. The patient gradually improved and is now, 8 months later, quite well on substitution therapy of Cortisone 25 mg. orally each day. As yet no signs of new metastases have developed and she is back at work at home.

Case 12. No. 372/51 and 337/53. I.L., a 38-year-old woman, had an attack of left-sided Jacksonian epilepsy 5 months prior to her first admission in May 1951. Two months before entry she had been operated on for a mammary carcinoma.

There was papillary edema of 4 D in the right eye and 2 D in the left. She had left-sided spastic hemiparesis with extensor response. Carotid angiography revealed a tumor in the right parietal lobe (Fig. 14A).

At operation a metastatic carcinoma, almost the size of a hen's egg, was easily extirpated.

Postoperative course was uneventful and the patient gradually improved. However, she still had Jacksonian fits, but with anti-epileptic therapy they were checked.

In April, 1953 she was readmitted. A tumor had developed in the operative scar on the vertex of the head. This tumor, the size of a walnut, was removed and proved

FIG. 14. *Case 12.* (A) Carotid angiography (May 1951) showing in the right parietal lobe a metastasis from a mammary carcinoma removed 2 months earlier. (B) Angiography (May 1953) 2 years after extirpation of the metastasis to the brain shows no evidence of intracranial recurrence, which was confirmed by encephalography.

on histological examination to be a metastasis. The patient had very slight left-sided hemiparesis. The eyegrounds were normal. Control carotid angiography at this time (2 years after removal of the intracranial metastasis) revealed no signs of recurrence (Fig. 14 B).

Owing to good results after removal of the pituitary gland in other cases of malignant tumors with metastases, a total hypophysectomy was performed in May 1953 as a prophylactic measure. The postoperative course was uneventful and the patient is now at home and quite well on substitution therapy of Cortisone.

CONCLUSIONS

The value of neurosurgery for brain metastases can be summarized as follows:

(1) The average postoperative survival period (10.5 months) is longer than in any earlier reports in the literature. (This figure includes the rather high postoperative mortality of 25 per cent within 20 days.)

(2) The survival period after onset of intracranial symptoms in one group (125 cases), in which the brain metastases had been operated upon, was compared with that in another group (33 cases) not operated upon. This was longer in the cases neurosurgically treated.

(3) Twenty-four cases in which the primary body growth had been removed before intracranial operation were compared with 101 cases in which the primary body tumor was still present at the time of brain operation. With regard to survival periods after onset of cerebral symptoms, and following brain operation, the results were better when the primary growth had been removed.

SUMMARY

A series of 158 cases of verified intracranial metastatic tumors have been investigated from a neurosurgical point of view. Various kinds of brain metastasis have been discussed with regard to pathology, clinical features, brain operation and survival periods. The following characteristic findings are outlined.

(1) Frequency of different pathological types of metastatic brain tumors: Hypernephroma 20 per cent, bronchial tumors 15 per cent, melanoma 8 per cent, and mammary carcinoma 7 per cent.

(2) Localization in the brain was most commonly in the frontotemporoparietal region and equal in both hemispheres.

(3) Operative findings: Enucleable tumors in 94 cases. Solitary tumors in 67 cases.

(4) Autopsy: Solitary brain metastasis in more than ⅓ of the cases examined.

(5) Clinical picture: Dominating initial symptoms were headache in 44 per cent, Jacksonian fits in 18, mental confusion in 8 and failing vision in 5 per cent of the cases.

(6) Patients can live for several years after extirpation of metastatic brain lesions. Average: 10.5 months. A patient with cerebellar metastatic hypernephroma is still alive more than 17 years after operation.

(7) Patients treated neurosurgically had a longer life expectancy than untreated ones.

(8) In cases in which the primary body growth had been removed before operation on the brain metastases, the postoperative survival was longer than in cases in which the primary tumor was still present at the time of brain operation.

(9) It is concluded that attempts to carry out radical neurosurgical

treatment are justified in patients suffering from intracranial metastatic tumors.

(10) Finally the recently developed therapy of metastatic tumors, hypophysectomy, is mentioned and the possibility of a combined attack with extirpation of the intracranial metastasis followed by hypophysectomy is discussed.

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CASE REPORT

UNUSUAL LOCAL COMPLICATION OF PERCUTANEOUS CEREBRAL ANGIOGRAPHY*

JEAN SIROIS, M.D., HENRI LAPOINTE, M.D., AND PAUL E. CÔTÉ, M.D.

Division of Neurological Surgery, and Department of Radiology, Enfant Jesus Hospital and Laval University, Quebec, Canada

(Received for publication June 29, 1953)

In the past few years the medical literature has been flooded with articles concerning cerebral angiography, but we could find no report of a local complication similar to the one presented herein.

Among the many local complications that have been described are cervical hematoma, irritation of cervical soft tissues, temporary paralysis of the vagus, transitory punctate hemorrhages in the face, neck or eyes, cervical radiculitis, irritation and paralysis of cervical sympathetic nerves,[1] external swelling, slight displacement of the trachea, tenderness at the puncture site and pain in moving the head and swallowing, and swelling and bruising of the mucous membrane of the pharynx.[2] None of these is directly related to an artery or could lead to difficulties in diagnosis.

In the following case the intima of the common carotid artery was injured by the needle during percutaneous angiography with the result that our clinical diagnosis was wrongly influenced and proper treatment of the lesion was not done.

CASE REPORT

Do. 115414. E.C., aged 50, was admitted as an emergency on May 1, 1953 at 8:00 P.M. For 5 weeks the patient had had increasing generalized headaches with progressive motor speech disturbances and weakness of the right limbs. Three days before admission he became somnolent and semiconscious in 24 hours.

Examination. The patient was deeply unconscious. Pulse rate was 44, and respiratory rate 12. There was slight swelling of the optic discs. The right pupil was slightly larger than the left and reacted sluggishly to light. Reflexes on the right were hyperactive with positive Hoffmann and Babinski signs on the right. Abdominal and cremasteric reflexes were abolished.

Clinical diagnosis: left-sided expanding lesion, probably temporal lobe tumour.

Percutaneous Carotid Angiography. Under intratracheal general anesthesia, puncture of the left carotid artery was easily performed. It may be mentioned that there was a strong flow of blood before each injection of diodrast during the procedure.

At the first injection visualization of the cerebral arteries was not obtained. As it was thought that this failure was caused by lack of timing the injections were repeated twice, with the same result. The radiologist, therefore, decided to place two films, one in the usual manner and a second at the neck in order to trace the course of the diodrast, since the operator was positive that the injections were made directly into the lumen of the artery, and there was no swelling of the neck. The angiogram obtained is shown in Fig. 1. A diagnosis of thrombosis of the internal carotid artery was made.

* Read at the meeting of the Canadian Neurological Society, Winnipeg, Canada, June 20, 1953.

FIG. 1. Occlusion of the common carotid artery, as shown in the upper of the two films used (see text). A valvula can be seen, or at least suspected, at the tip of the needle.

With the next injection the entire common carotid was visualized from its origin, and it was thought that the thrombosis began a few mm. from the bifurcation (Fig. 2). This film also eliminated the possibility of an intramural injection of the dye, for in such instances the artery appears to be blocked but is much larger than usual.

Although this last film (Fig. 2) was quite in favor of a thrombosis, the diagnosis was not satisfactory because of the clinical findings and history of the patient.

A right percutaneous angiography was performed. The elevation of the left middle cerebral artery and the displacement to the right of the right anterior cerebral artery sug-

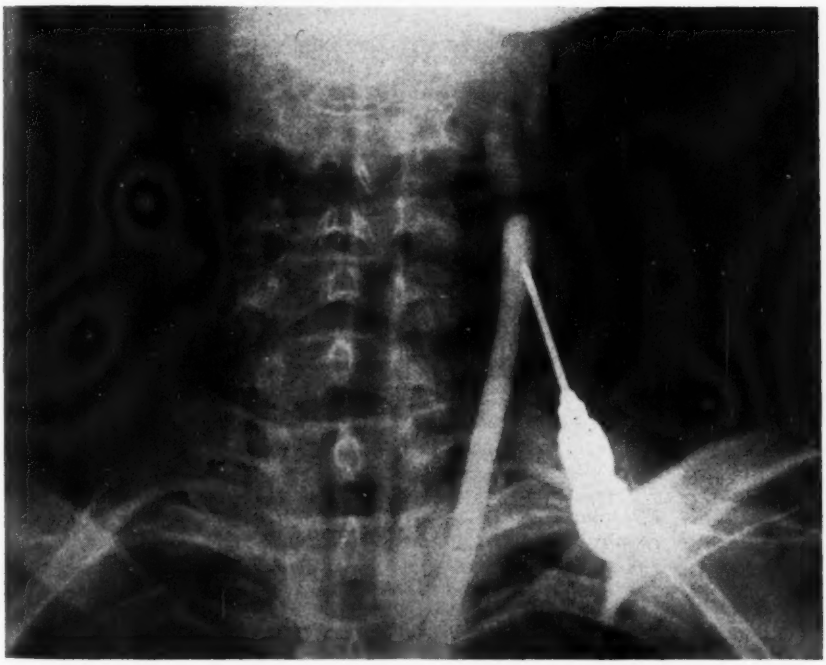

FIG. 2. The entire common carotid artery is filled. A few mm. from the bifurcation, the internal carotid artery seems to be obliterated. The valvula is less evident than in Fig. 1.

FIG. 3. The left common carotid artery and bifurcation into internal and external carotid. Note the two holes and the neat cut made horizontally. The peeling of the adventitia formed a valvula in which the blood and the dye were blocked.

gested an expanding lesion in the left temporal lobe. However, the diagnosis of thrombosis of left internal carotid artery prevailed and also because of the poor condition of the patient it was decided not to carry out trephine exploration of the left temporal lobe.

The following morning, the patient died.

Autopsy revealed that the clinical diagnosis was accurate; there was a large spongioblastoma of the left temporal lobe.

The X-ray findings of the left angiography were understandable on examination of the common carotid artery on the left side. As shown in Fig. 3, there are two little holes in the artery and, just above, the intima of the artery has been sharply and neatly cut horizontally for about $\frac{1}{3}$ of the entire diameter of the intima. This caused a peeling of the adventitia which formed a valvula, the opening end of which faced the blood flow.

When the artery was closed (Figs. 4 and 5) the flow of the blood dilated the valvula and obliterated the artery so that the diodrast was forced down stream.

FIGS. 4 and 5. (*Left*) On closing the artery the cut end of the intima is lifted and the valvula is opened. (*Right*) As shown, the valvula can be slightly dilated. The blood flow dilated the valvula, especially during the injection, as shown in Fig. 1 with the needle apparently inside the valvula. This dilatation caused obliteration of the artery and suggested the diagnosis of a thrombosis.

If the angiograms (Figs. 1 and 2) are closely studied, one may suspect the valvula, dilated with the diodrast, with the point of the needle at its opening. Had we known that such a valvula could result from the puncture, we would have maintained our first diagnosis of a left temporal tumour.

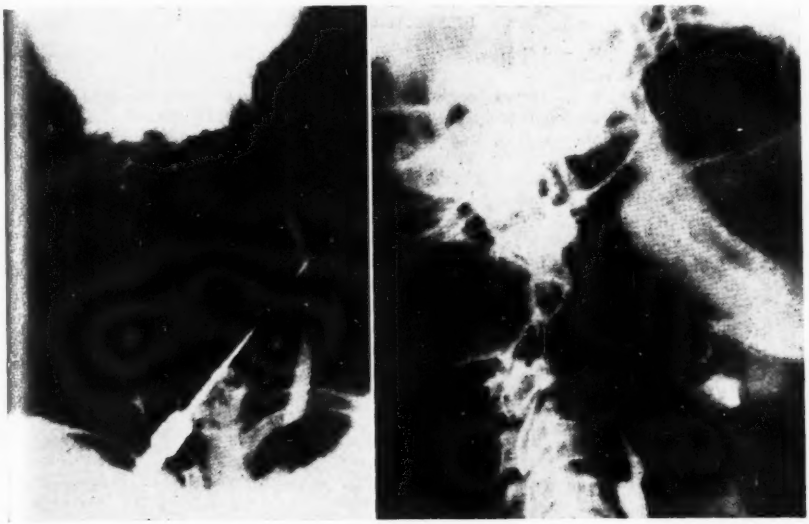

FIG. 6. (Reproduced from Koppang[6]) There seems to be a slight dilatation at the site of the blockage, which appears clearer on the lateral view. The point of the needle, as in our Figs. 2 and 3, would have an identical position.

COMMENTS

1. It is quite interesting to compare with our findings some of the angiograms published in articles on the diagnosis of thrombosis of carotid arteries.[3,4] For example, an illustration in a paper by Koppang[5] seems to show a similar kind of tip of the contrast medium (Fig. 6).

One may wonder (a) if the formation of a valvula by a ruptured intima of the artery is more frequent than supposed, and (b) if one should, as a routine, puncture the internal carotid artery every time percutaneous angiography of the common carotid shows a block, or even expose the internal carotid artery to verify the thrombosis, so as to be sure to eliminate the possibility of a traumatic valvula of the intima.

2. We think that the intima of the artery was punctured by the tip of the needle and then the cross section was made by a lateral movement of the needle. The force of the blood flow was enough to peel the intima and form the valvula (Fig. 7).

It therefore seems appropriate to advise the use of a needle with a short point that is as dull as possible in order to avoid such damage and to prevent the possibility of obtaining a film that may lead to the wrong diagnosis of thrombosis.

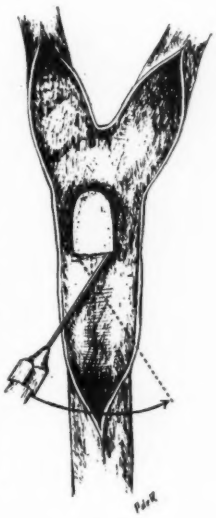

FIG. 7. Drawing to show how the point of the needle may have cut the intima by a lateral movement during the manipulations.

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NOTICES

AMERICAN BOARD OF NEUROLOGICAL SURGERY

The American Board of Neurological Surgery at its meeting in New Haven, Connecticut, October 21–24, 1953 discussed the problem of evaluating residency training programs throughout the country. As stated in the July 1953 issue of the *Journal* (p. 441), a Residency Review Committee has been established as a joint activity of the American Board of Neurological Surgery and the Council on Medical Education and Hospitals of the American Medical Association. The members of the Residency Review Committee are Drs. Francis C. Grant, R. Glen Spurling, and Leonard T. Furlow from the Board, and Drs. Paul Bucy, Ottiwell W. Jones, Jr. and Edward Leveroos from the Council on Medical Education and Hospitals.

Since all residency training programs are to be reviewed, a new type of questionnaire has been devised and this will be sent from the Council office to all approved neurosurgical residency training programs. The Board is cognizant of the fact that the filling out of such a questionnaire entails considerable time and work on the part of the hospital and the chief of the neurosurgical service. It is necessary, however, that this information be obtained from every service in order that the evaluation may be carried out in an orderly fashion. The Board is very anxious that these questionnaires be filled out and returned to the Council office as promptly as possible.

Examinations were given by the American Board of Neurological Surgery, October 22–24, 1953, in New Haven, Connecticut, and the following were certified:

AMMERMAN, HARVEY H. 2025 Eye St., N.W., Washington 6, D. C.
ARNSTEIN, LAWRENCE 605 Cowper St., Palo Alto, Calif.
BATKIN, STANLEY University Hospital, Syracuse 10, N. Y.
BIDWELL, ROBINSON LeR. II 203 State St., Portland, Me.
BRZUSTOWICZ, RICHARD JOHN 277 Alexander St., Rochester 7, N. Y.
BUSHARD, MARCUS C. 3374 Fourth Ave., San Diego, Calif.
COHN, GEORGE ALTMAN 993 Delaware Ave., Buffalo 9, N. Y.
DRUCKEMILLER, WILLIAM HENRY U. S. Navy
DUNSMORE, REMBRANDT HARVEY 85 Jefferson St., Hartford 14, Conn.
EAGLES, WILLIAM McCOY Veterans Administration Hospital, Richmond 19, Va.
ENGLISH, HOWARD S. 1611 Genesee St., Utica, N. Y.
ESTRIDGE, M. N. 207 Platt Bldg., San Bernardino, Calif.
GARCIA OLLER, JOSE L. 3326 Nashville Ave., New Orleans, La.
GREENE, CLARENCE SUMNER 3939 Military Rd., N.W., Washington, D. C.
GUSTILO, ROMEO H. Santo Tomas University Hospital, Manila, Republic of Philippines
HARPER, W. HENRY 638 East Santa Clara St., San Jose, Calif.
HENRY, MARSHALL G. 1006 Hermann Professional Bldg., Houston 5, Texas
HINCHEY, THOMAS P. R. 1101 Beacon St., Brookline, Mass.
HORNING, EDWARD DOUGLAS 18 West Franklin St., Baltimore 1, Md.
HUERTAS, JORGE (Foreign certificate) Cra 9 No. 48-68, Bogota, Colombia
KIRGIS, HOMER D. Ochsner Clinic, New Orleans, La.
MALIS, LEONARD I. 1185 Park Ave., New York, N. Y.
MANNING, GEORGE C., JR. 111 Medical Center Bldg., Fort Wayne, Ind.
MULFORD, EDWIN HASTINGS II 144 Golden Hill St., Bridgeport, Conn.
ROBINSON, FRANKLIN 250 Edwards St., New Haven, Conn.
SAYERS, MARTIN PETER 9 Buttles Ave., Columbus 8, Ohio
SCHEIBERT, CHARLES DAVID Box 93, Kennedy Hospital, Memphis 15, Tenn.
SLEPIAN, ALEXANDER 959 Lafayette Ave., Niagara Falls, N. Y.

STARR, HARRY 675 Fifth St., Beaumont, Texas
STRATEMEYER, WINSLOW P. 415 E. Yandell Blvd., El Paso, Texas
TSANG, JOHN L. K. 919 N. Taylor Ave., St. Louis, Mo.
ZUNIGA, ARCESIO (Foreign certificate) 605 Commonwealth Ave., Boston 15, Mass.

ASSOCIATION FOR RESEARCH IN NERVOUS AND MENTAL DISEASE

At the 33rd annual meeting of the Association for Research in Nervous and Mental Disease held in New York City on December 11–12, 1953, the following officers were elected for the year 1954: President, Dr. Rustin McIntosh; 1st Vice-President, Dr. Walter Klingman; 2nd Vice-President, Dr. William S. Langford; Secretary-Treasurer, Dr. Clarence C. Hare; Assistant Secretary, Dr. Rollo J. Masselink.

The subject for the 1954 meeting will be "Psychiatry and Neurology of Childhood."

CONGRESS OF NEUROLOGICAL SURGEONS

The 3rd annual meeting of the Congress of Neurological Surgeons was held in New Orleans at the Roosevelt Hotel, November 12–14, 1953.

Sir Geoffrey Jefferson was the distinguished guest and his papers included Changing Ideas on the Integration of the Brain, Trigeminal Tumors, and Chiasmal Gliomas.

The following officers were elected: James R. Gay, White Plains, N. Y., President; Donald B. Sweeney, Birmingham, Vice-President; and Bland W. Cannon, Memphis was re-elected Secretary and Treasurer. The members of the Executive Committee continued in office were Frederick C. Rehfeldt, Fort Worth, Donald B. Freshwater, Pasadena, Raymond K. Thompson, Baltimore and Ira J. Jackson, Galveston. Franklin Earnest, III, Toledo and Henry M. Suckle, Madison, were newly elected to the Executive Committee.

NEUROSURGICAL SOCIETY OF AMERICA

At the 6th annual meeting of the Neurosurgical Society of America held at the Broadmoor, Colorado Springs, Colorado, September 23–26, 1953, the following officers were elected: President, C. Douglas Hawkes, Memphis; Vice-Presidents, Carl J. Graf, Buffalo and Charles L. Neill, Jackson; Treasurer, I. Joshua Speigel, Chicago; and Secretary, Lester A. Mount, New York.

THE TREATMENT OF GLIOBLASTOMAS WITH RADIUM

ERNEST SACHS, M.D.*
New Haven, Connecticut

(Received for publication May 5, 1953)

BETWEEN the years 1911 and 1946, 789 gliomas of various types were treated in my clinic. They were subdivided into the following groups:

256 Astrocytomas, some solid and some cystic
92 Medulloblastomas
32 Cysts with no microscopic verification
52 Ependymomas
39 Oligodendrogliomas
57 Various rarer types
261 Glioblastomas

I think I am expressing the opinion of most neurosurgeons that all gliomas other than the glioblastomas should be operated upon and removed as radically as possible. As many grow slowly repeated operations may be undertaken to prolong the patient's life. Views about medulloblastomas vary in that some surgeons content themselves with a biopsy and then use intensive X-ray therapy, while others remove the tumor as completely as possible and then give X-ray therapy. Whether radiation should be used following operation for other types of tumors is a question about which there still is a difference of opinion. With a slowly growing tumor that has been radically removed it is extremely difficult to determine what effect radiation has had on the course of the disease.

Our greatest problem, however, still remains the care of patients with glioblastomas and I shall limit my remarks to this group. Let me say in the first place what I have repeatedly said before, that I believe every patient with a brain tumor is entitled to an exploration to determine what can be accomplished by surgery. I am not convinced that by angiography one can positively diagnose a glioblastoma though I realize that the claim has been made. Nor can the preoperative diagnosis be definitely made on the history and course of the disease, though it may frequently be suspected.

Of the 261 cases of glioblastomas in this series it has been possible to review only 154 at this time. The histories of the others are still in St. Louis. However, the 154 cases that have been reviewed are enough to enable one to draw some conclusions.

* Research Associate, Departments of Surgery and History of Medicine, Yale University School of Medicine, New Haven, Connecticut. Formerly Professor of Clinical Neurological Surgery, Washington University School of Medicine, St. Louis, Missouri.

The majority of the patients with glioblastomas died in less than 2 months but there were 14 who lived for over a year and these have been studied particularly to determine what factor or factors were responsible for their longer survival. Of this pitifully small number, 8 lived more than 2 years and 4 for more than 3 years.

The first question to resolve was the histological character of the tumors in these cases of longer survival. The sections were therefore re-examined. From their microscopical appearance all of the tumors were malignant. They contained numerous mitoses, showed endothelial and adventitial proliferation of the blood vessels, and in some there was necrosis with pseudopalisading. We may conclude therefore that they were histologically as malignant as in those cases in which the patients died much more quickly. The location of the tumors was of no apparent significance; some were frontal, some parietal, some temporal, and one was occipital.

Then the treatment was considered. What, if anything, was different in the handling of these tumors as compared to the others in the series?

The longest survival was in those cases in which a very large amount of radiation was given. In 1937 and 1939 three papers on the radiation of gliomas were published from my clinic. One was a study of the effect of X-ray on tumors, reported in 1937.[1] That same year a technique was described[2] by which one could give one massive dose of X-ray into an open wound at the time of operation. The largest dose we gave in this way was 6000 r. But the method was cumbersome and technically awkward. The skin wounds, of course, had to be very carefully protected so that they healed well and were not injured by this large amount of radiation. In 1939[3] 119 gliomas were reviewed and the conclusion was reached that heavier doses of radiation than we had been giving would have to be employed to get any effect. At that time the usual dosage was 1500 to 2500 r.

We then began treating a series of patients by implantation of gold radon seeds into the raw surface of the brain from which all vestiges of tumor had been removed. The seeds were placed within 1 cm. of each other. In the first cases 10 to 12 seeds were used, but subsequently the number was increased to 40 seeds. The amount of radiation that the patient received by this method in a localized area is much greater than it is possible to give with X-ray, as calculated by Dr. Shapiro of the Department of Radiology at Yale University School of Medicine.

In the following brief reports, Cases 1 and 2 illustrate the advantages of using radon seeds instead of X-ray radiation, and Case 3 demonstrates that the size of the radiation dose plays an important role.

Case 1 (51203). A female, aged 26, was admitted with Jacksonian convulsions of her arm. She was operated upon but no tumor was found, so a subpial resection of her arm center was performed. Three months later she returned with the typical picture of an intracranial tumor. A radical operation was performed and she was given 2500 r of X-ray. She returned in 2 months with symptoms of a recurrence. Reoperation was performed and 30 radon seeds were implanted. The radiation amounted to 8500 r. Following this treatment she lived for 2½ years.

Case 2 (47539). A male, aged 26, had had a radical removal of a temporal tumor

and was readmitted 3 months later for a recurrence. After a second removal 40 radon seeds were implanted, representing a dosage of 11200 r. He went along for 2 years and 2 months and then returned with another recurrence. He was again operated upon but this time a dosage of 3500 r of X-ray was administered through the open wound. He died of a recurrence 5 months later.

Case 3 (57301). A female, aged 40, after removal of a temporal lobe tumor received 6000 r through the open wound. She lived for $2\frac{1}{2}$ years.

These patients and some of the others who survived well beyond the average time demonstrate quite clearly that large amounts of radiation are tolerated and have a beneficial effect. The great advantages of using radon seeds are that the radiation is concentrated in the region in which it is most needed and that the rest of the brain is not affected by the radiation. Placing the radon seeds in a flat surface, as when a frontal lobe has been amputated, is much more satisfactory than if one has a cavity left after a tumor has been removed. It is difficult to place seeds into such a cavity so that the entire area receives intensive radiation without any gaps, and this I believe may be the reason why some patients in whom we put seeds did not survive so long a time. It is most important to place the seeds close together, as the radiation from seeds extends only a short distance, not more than 1 cm. in every direction.

If one has no emanation plant at hand, and we had none nearer than Chicago, it is cumbersome to make arrangements for getting seeds but we were able to obtain them 24 hours after they had been prepared and each seed amounted to 1 millicurie. We had no experience in applying radium externally but in Stanford Cade's book[1] on the treatment of malignant disease by radium, there is a record of 4 patients with glioblastomas who were operated upon by Hugh Cairns and treated for him by Cade. They lived 9, 6, 5, and 5 years respectively. In all of these cases the dosage was around 8000 r. He reported no cases of brain tumors that were treated with radon seeds but mentioned the possibility.

Our cases and those of Cairns, it seems to me, indicate quite definitely that we must make a more determined effort to treat glioblastomas with radium since it is possible to give much bigger quantities of radiation than with X-ray.

With this evidence I feel we are not justified in considering the glioblastomas a hopeless problem but rather one that needs more intensive effort to effect a cure. It would be most interesting if some clinic would undertake to treat two series of glioblastomas, one with radon seeds and another with radium or cobalt, in the form of a helmet, as described by Cade.

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CONTROLLED PNEUMOENCEPHALOGRAPHY

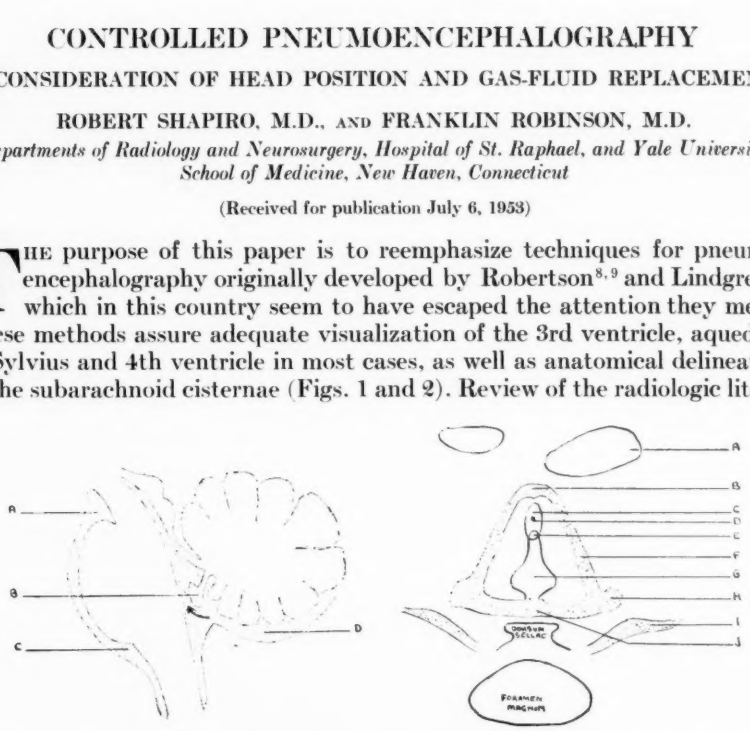
A CONSIDERATION OF HEAD POSITION AND GAS-FLUID REPLACEMENT

ROBERT SHAPIRO, M.D., AND FRANKLIN ROBINSON, M.D.

Departments of Radiology and Neurosurgery, Hospital of St. Raphael, and Yale University School of Medicine, New Haven, Connecticut

(Received for publication July 6, 1953)

THE purpose of this paper is to reemphasize techniques for pneumoencephalography originally developed by Robertson[8,9] and Lindgren[4,5] which in this country seem to have escaped the attention they merit. These methods assure adequate visualization of the 3rd ventricle, aqueduct of Sylvius and 4th ventricle in most cases, as well as anatomical delineation of the subarachnoid cisternae (Figs. 1 and 2). Review of the radiologic literature shows that the problem of visualizing the posterior midline structures is a significant one as evidenced by the numerous complicated positional maneuvers that have been devised[11,13] and the recent extensive use of tomography.[2,6,7,12]



FIGS. 1 and 2. (*Left*) Scheme of roof of lateral ventricle and cisterna magna. Arrow in the foramen of Magendie (after Gray). A = Cisterna interpeduncularis. B = Choroid plexus of 4th ventricle. C = Cisterna pontis. D = Cisterna magna.

(*Right*) Tracing of a postero-anterior upright roentgenogram showing the posterior midline structures and the subarachnoid cisternae. A = Lateral ventricle. B = Cisterna vena magna cerebri. C = Third ventricle. D = Pineal gland. E = Aqueduct superimposed on posterior portion of 3rd ventricle. F = Cisterna ambiens. G = Fourth ventricle. H = Lateral recess of pontine cistern. I = Air between cerebellum and petrous portion of temporal bone. J = Cisterna magna and cisterna pontis superimposed.

The technique of encephalography varies considerably; this is true of the actual roentgenological technique as well as the methods of gas-fluid replacement. The common practice appears to be the drainage of a variable amount of spinal fluid before gas is introduced into the lumbar subarachnoid space. Thus, Davidoff[1] recommended the initial removal of 10 cc. of cere-

brospinal fluid prior to replacement with 5 cc. of gas. Thereafter, 5 cc. aliquots of fluid and gas are alternately removed and injected. With this method, 50–70 cc. of gas are employed for routine pneumoencephalography. Other examiners use even larger quantities of gas and, in some clinics, it is not uncommon for encephalography to be done with complete replacement of the cerebrospinal fluid by gas.

As early as 1933, Gardner and Nichols[3] stated that satisfactory filling of the ventricular system could be obtained if air were injected into the lumbar theca prior to removal of fluid. More recently, Lindgren[4] has demonstrated that ascent of gas to the 4th ventricle and aqueduct is enhanced when no fluid is initially removed. Similarly, Lindgren[4,5] and Robertson[9] have shown that ascent of gas into the ventricular system depends upon the position of the head. Nevertheless, these observations do not appear to be generally known nor appreciated.

PRINCIPLES OF TECHNIQUE

Gas introduced into the lumbar theca ascends to the cisterna magna when the patient is seated with the head flexed. Thereafter, its course is determined by the position of the head (Fig. 3). Thus, with the head in the neutral or

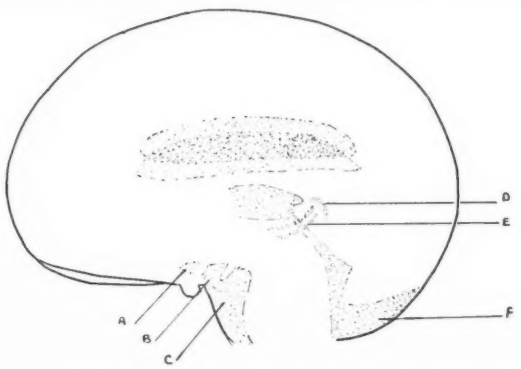


FIG. 3. Tracing of a lateral view of a roentgenogram showing the basilar cisternae. A=Cisterna chiasmatis. B=Cisterna interpeduncularis. C=Cisterna pontis. D=Cisterna vena magna cerebri. E=Cisterna ambiens. F=Cisterna magna.

slightly extended position, most of the gas passes ventrally into the basilar cisternae. From there, it may either go posteriorly into the cisterna ambiens or anteriorly into the cisterna chiasmatis (Fig. 4). However, if the head is flexed acutely, gas tends to enter the posterior portion of the cisterna magna and pass over the dorsal aspect of the cerebellum; from there it proceeds forward under the tentorium to the cisterna venae magnae cerebri and finally upward over the cerebral convexity. Little gas enters the basilar cisternae in the position of hyperflexion of the head; also there is little opportunity for ventricular filling with the head in this position. The ideal position is one

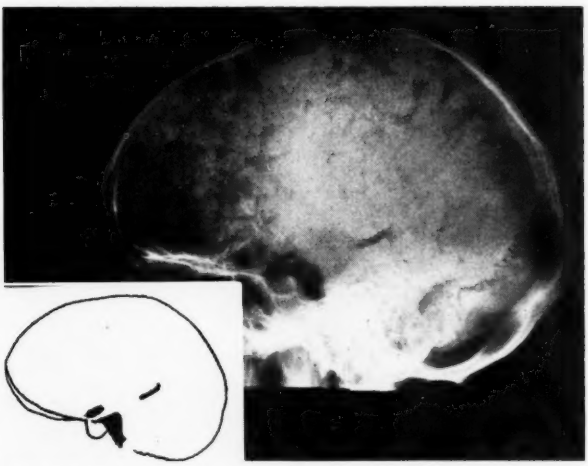
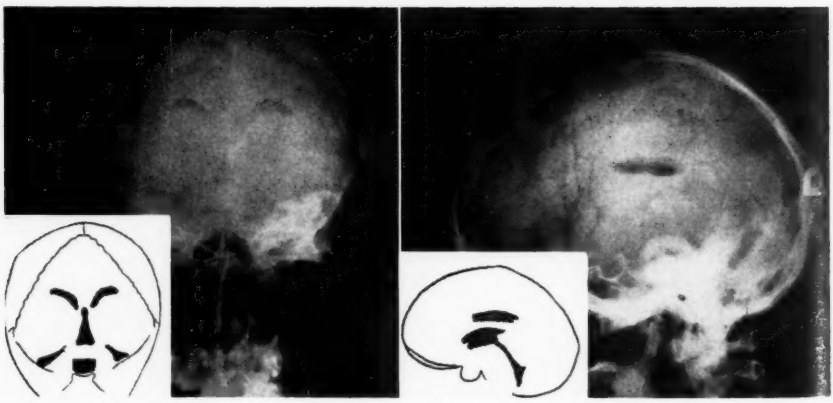


FIG. 4. Lateral film of skull with head in the neutral position, showing air in the basilar cisternae and the cisterna ambiens.

of slight flexion of the head; under these circumstances, gas rises to the anterior portion of the cisterna magna to ascend through the foramen of Magendie to the 4th ventricle, aqueduct and posterior portion of the 3rd ventricle (Figs. 5 and 6). Initial drainage of cerebrospinal fluid probably results in a variable degree of collapse of the cisternae and foramina which mitigates against successful ascent of gas into the ventricular system. Robertson's experience has shown that successful ventricular filling depends upon the tendency of gases to rise vertically in liquids. It is reasonable, therefore, to expect that ventricular filling would be achieved more uniformly with the subarachnoid spaces distended.

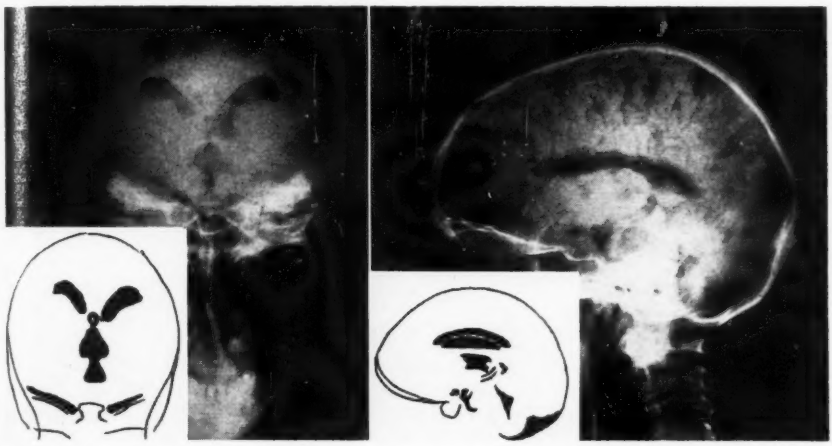


FIGS. 5 and 6. Postero-anterior and lateral views of skull with head in slight flextion, showing air in the 4th ventricle, aqueduct of Sylvius and posterior portion of 3rd ventricle (8 cc. of air).

TECHNIQUE OF EXAMINATION

Lumbar puncture is performed with the patient seated and the head slightly flexed (approximately 20°) facing the vertical cassette holder of the x-ray unit. After the escape of several drops of spinal fluid from the needle, 5–8 cc. of filtered air are slowly injected. Postero-anterior and lateral roentgenograms with the head in the same position are taken and viewed. There is usually excellent visualization of the 4th ventricle, aqueduct and posterior portion of the 3rd ventricle, and partial filling of the lateral ventricles. Should visualization of the posterior midline structures not be satisfactory, minor adjustment of the position of the head may be required. The degree and type of adjustment are governed by the location of the injected air.

Approximately 5–8 cc. of cerebrospinal fluid are removed before the injection of additional air. If the posterior midline structures are demonstrated satisfactorily on



FIGS. 7 and 8. Postero-anterior and lateral views of skull following the introduction of 20 cc. of air.

the preliminary films (and they usually are), an additional injection of 10–15 cc. of air is made; the last 5 cc. are injected with the head in the neutral position so that air flows into the ventral basilar cisternae. If it is desirable to visualize the sulci over the cerebral convexities, 5–10 cc. of air may be injected with the head markedly flexed so that air may pass over the dorsal aspect of the cerebellum and finally over the cerebral hemispheres (Figs. 7 and 8). The total quantity of air routinely employed rarely exceeds 20–30 cc.

The patient is then placed in the supine position with the frontal horns up and the following films are made:

1. Anteroposterior projection with the central ray passing through the frontal horns.
2. Anteroposterior half-axial projection (tube tilted 30° toward the feet). This provides an elongated view of the frontal horns which demonstrates the septum pellucidum well.
3. Lateral projection.

The patient is turned slowly into the prone position with the occipital horns up in order to visualize the posterior portions of the lateral ventricles, and the following roentgenograms are made:

4. Postero-anterior projection with the tube tilted 10° toward the head.
5. Postero-anterior half-axial projection (reverse Chamberlain-Towne position) with the tube tilted 30° toward the head. This view is optional.
6. Lateral projection.

The temporal horns are filled with air by slowly turning the patient from the prone position with the chin held close to the chest and the head slightly inclined downward and laterally. With this maneuver the air passes along the floor of the lateral ventricle into the corresponding temporal horn where it remains trapped when the patient finally reaches the supine position. The following films are made for study of each temporal horn:

7. Anteroposterior or postero-anterior projection.
8. Lateral projection.

Several anteroposterior projections of the temporal horns may be made with varying degrees of tube angulation if special attention is required because of suspected lesion in this region.

The examinations frequently were conducted with manometric control of the cerebrospinal fluid pressure. The average spinal fluid pressure in the sitting position ranged from 310–570 mm. of water. The introduction of 5–8 cc. of air was accompanied by a rise in manometric pressure varying from 30–170 mm. of water (average = 90 mm.). The transient rise in pressure was corrected by drainage of cerebrospinal fluid under manometric control so that the spinal pressure was restored to its pre-injection level, and similarly corrected following each subsequent incremental air injection.

DISCUSSION

Experience has proven this method to be far superior to the blind, relatively uncontrolled replacement of cerebrospinal fluid with large quantities of gas. The authors completely agree with Lindgren that encephalography is a procedure that requires detailed attention and constant direction, if consistently good results are to be achieved.

The advantages of this technique are (1) precise direction of air into the ventricular and cisternal systems, thus assuring anatomical visualization of these structures and eliminating the need for complicated special positions or tomography; (2) low morbidity—it has been found that little or no post-encephalographic discomfort is experienced when small amounts of air are employed so that it has not been uncommon for patients to be ambulatory several hours after examination.

To date, most of the patients examined have had either seizure problems or craniocerebral injuries. There were 4 patients with expanding intracranial mass lesions (2 intracerebral hematomas, 1 chronic subdural hematoma, 1 temporal glioblastoma multiforme) who did not have either clinical or manometric evidence of increased intracranial pressure. These patients tolerated the procedure without any untoward effects. At present, we do not advocate the routine use of this technique in patients with obvious expanding intracranial mass lesions. However, other investigators[5,10] have reported the use of a similar method without adverse results in patients with increased intracranial pressure.

SUMMARY

1. A pneumoencephalographic technique for filling the 4th ventricle, aqueduct and subarachnoid cisternae with small amounts of air is reviewed.

2. The advantages of this method are discussed.

3. The roentgenological anatomy of the subarachnoid cisternae is presented.

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THE PATHOLOGIC ANATOMY OF RUPTURED CEREBRAL ANEURYSMS*

GEORGE WILSON, M.D., HELENA E. RIGGS, M.D., AND CHARLES RUPP, M.D.
Laboratory of Neuropathology, Philadelphia General Hospital, Philadelphia, Pennsylvania

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INCREASING interest in the surgical treatment of cerebral aneurysms suggests that an evaluation of the potentialities of this form of therapy might be aided by a review of some of the anatomic findings in 143 autopsied cases of subarachnoid hemorrhage caused by leaking miliary or berry aneurysms of the circle of Willis.

The sex and age distribution in this group differed significantly from that in cases of apoplexy previously reported.[5] Women predominated 91 to 52; 31 per cent of the patients were under 40 years of age as compared to 9 per cent in the apoplectic group. The youngest patient was 14 and the oldest 94.

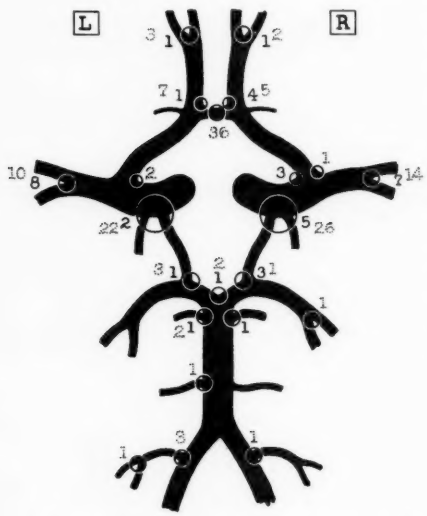

FIG. 1. Showing location of aneurysms on the circle of Willis: 143 ruptured aneurysms (dotted numerals) and 39 unruptured aneurysms (solid numerals).

The aneurysms were all located above the carotid siphon on the circle of Willis, its peripheral branches or its basivertebral component. Forty-eight involved the anterior communicating artery, 51 the internal carotid, 30 the branches of the anterior, middle or posterior cerebral arteries, and 14 the basivertebral stems. The left half of the circle was involved in 54 cases, the right in 51 and the midline in 38 (Fig. 1).

The aneurysmal sac originated at arterial branchings, although not necessarily at a bifurcation, in 101 cases and by outpouchings from the vascular stem in 42. When the aneurysms involved the origin of an artery, particularly the anterior choroidal from the internal carotid, the distal portion of the vessel was frequently continuous with the fundus of the sac.

Multiple Aneurysms. Multiple aneurysms were present in 27 patients, bilaterally placed in 13 and in the midline as well as on one or both sides in 7. Ruptured and unruptured sacs were found on the same artery in 2, on the

* Read in part at the First International Congress of Neuropathology, Rome, September 13, 1952.

same side of the carotid stem in 7 and on the basivertebral branches in 7.

Meningeal Hemorrhage. Bleeding into the subarachnoid space was found at necropsy in 137 patients. Evidence of ancient leakage was noted in 6 patients dying of causes unrelated to aneurysmal rupture. Bleeding into the basal cisterns occurred in the majority of cases but was confined to the convexity on the side of the aneurysm in 12, to the median fissure in 7 and localized to the immediate region of the sac in 10. Subdural extension occurred in 22 cases.

Continued leakage or recurrent hemorrhage from the aneurysmal sac apparently occurred in 121 patients. Resolution of the bleeding, manifested by staining of the meninges and hemolyzed blood around the basal structures, was found in only 6 patients, 2 of whom died within 5 days after the onset. Recent bleeding or fresh hemorrhage superimposed on older clots was present in 26 patients who had been hospitalized longer than 1 week and 12 with symptoms of 2 to 6 weeks' duration. Signs of older leakage, obviously antedating the episode of acute bleeding, could be demonstrated in many instances. Bronzing of the meninges, infiltration of tissue around the sac by blood pigment and collections of similar pigment along the basal vessels were noted in 13; envelopment of the aneurysm, wholly or partially, by a pseudo sac in 22; and dense adhesions between the sac and the arteries or adjacent structures in 25.

Parenchymatous Lesions. Destruction of brain tissue, more extensive than erosion or hemorrhage around the sac, complicated the rupture of the aneurysm in 94 cases. Frank hemorrhage occurred in 29 cases, as a subcortical hematoma contiguous to the aneurysm in 21, and deep within the brain structures at a distance from the sac in 8. Focal hemorrhagic or anaemic infarction involving both cortical and deep structures, frequently in more than one area, was present in 65.

Disregarding the nature of the parenchymatous destruction (hemorrhage or infarction), the site of the lesion, in the majority of cases, could be correlated with the location of the aneurysm on the cerebral vascular tree.

Aneurysms arising from both the anterior cerebral and the anterior communicating arteries were associated with damage to the medial portion of the frontal lobe and the corpus callosum, with additional involvement of the orbital portion of the frontal lobe and the caudate nucleus in cases of aneurysms of the anterior communicating artery. The cortex and subcortex of the convexity were involved with aneurysms of the middle cerebral in the Sylvian fissure. Lesions in this area, as well as of the lenticular region and the subependymal tissue around the inferior horn of the ventricle were present with aneurysms of the internal carotid. Destruction within the cerebellar hemisphere and damage to the retro-olivary portion of the medulla, respectively, was noted with two aneurysms arising from the basivertebral stem, one at the origin of the superior cerebellar and the other at the origin of the posterior inferior cerebellar. Lesions of the midbrain and upper pons occurred with aneurysms of the divisional branches of the basilar.

In general, the parenchymatous damage associated with leaking aneu-

rysms occurred in the territory of stem vessels located distal to the sac. It would seem, therefore, that circulatory disturbances in the vascular bed of the peripheral field of supply resulting from aneurysmal rupture must be considered as a factor in the production of the brain lesions. However, lesions confined totally or in part to the distribution of ganglionic arteries were associated with 10 aneurysms of the middle cerebral in the Sylvian fissure, and bilateral lesions of the globus pallidus with unilateral destruction of the cortical grey ribbon of the island of Reil with an aneurysm of the anterior communicating. In view of these findings, other factors, such as rapidly increasing intracranial pressure, may also contribute sufficient circulatory disturbance to produce tissue damage in susceptible areas.

Extraneural Disease Associated with Leaking Cerebral Aneurysm. We have previously reported that, although aneurysms were present in 131 of a series of 1,335 brains examined at necropsy, leakage or rupture was present in only 37 (28 per cent).[2] Little attention has been paid to the factors that precipitate bleeding from cerebral aneurysms. The etiologic role of cardiovascular or other chronic organic somatic disorders is difficult to evaluate in elderly patients. It seems worthy of mention, however, that hypertrophy of the heart, particularly of the left ventricle, was present in 27 of the group of 40 patients under 40 years of age. Dissecting aneurysm of the aorta, severe coronary sclerosis or fibrosis of the myocardium were present in 3 patients, the oldest of whom was 30. Rheumatic valvular disease was noted in 3, pericardial effusion in 2 and adhesive pericarditis in 1—all under 40 years of age. In this younger group, subarachnoid bleeding occurred during active pulmonary tuberculosis in one patient and during a crisis of sicklemia in another.

Of the 97 patients over 40 years of age, 41 were under treatment for cardiac disorders prior to the onset of the subarachnoid bleeding; 15 additional instances of luetic or rheumatic heart disease were found post mortem. Patent foramen ovale was noted in 3 cases, pericardial effusion in 1 and a large aneurysm of the aortic arch in another. Subarachnoid bleeding occurred in 3 chronic alcoholics during a debauch and in 1 patient at the onset of diabetic acidosis.

Associated Anomalies. Extracranial anomalies and malformations have frequently been reported as associated with cerebral aneurysms[4] but were present in only 9 patients in this group. Patent foramen ovale or fenestration of the aortic valves was noted in 4, polycystic disease of the kidney in 1, and horseshoe kidney in another. Hypoplasia of one kidney or one adrenal was noted twice, reduplication of the ureter, once.

Anomalous formation of the circle of Willis in the presence of cerebral aneurysm, however, was present in 118 of the 124 cases in which complete description was available. Because of the relatively few cases in which the posterior half of the circle of Willis was involved, analysis of the intracranial anomalies associated with leaking aneurysms is limited to 119 cases in which the aneurysmal lesion involved the internal carotid or its branches. Essentially, the anomalous formation resulted from hypoplasia of one or more of

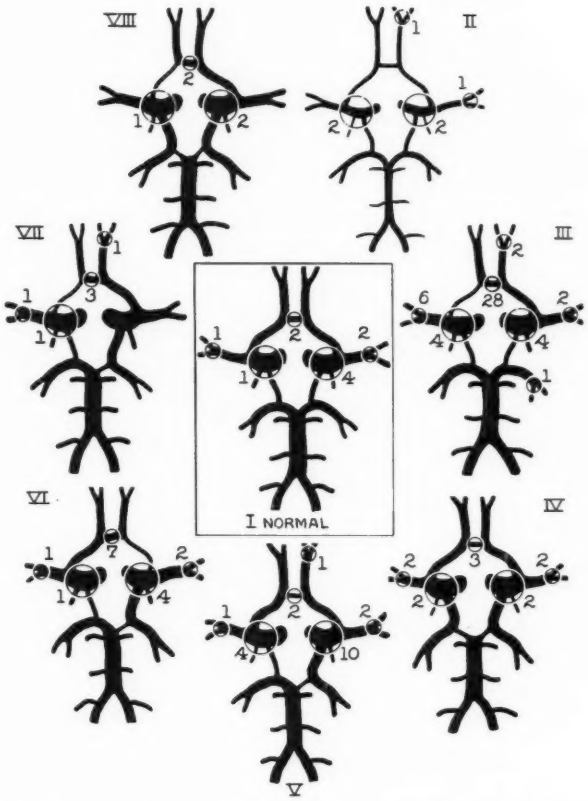

FIG. 2. Variations in circle of Willis associated with 114 cases of ruptured miliary aneurysm.

I. Normally formed circle of Willis—10 cases.

II. Hypoplasia of all stem vessels which are relatively equal in size (foetal type)—6 cases.

III. Hypoplasia of the first portion of one anterior cerebral artery—47 cases.

IV. Hypoplasia of the divisional branches of the basilar artery on both sides, with origin of both posterior cerebral arteries from the internal carotid stem—11 cases.

V. Hypoplasia of the divisional branch of the basilar artery on one side, with origin of the posterior cerebral artery of the same side from the internal carotid stem—20 cases.

VI. Hypoplasia of the first portion of the anterior cerebral artery and of the divisional branch of the basilar on the same side with the posterior cerebral artery of that side originating from the internal carotid stem—15 cases.

VII. Hypoplasia of the first portion of one anterior cerebral artery, and of the divisional branch of the basilar on the opposite side, the posterior cerebral artery originating from the internal carotid stem on the side of the hypoplastic divisional artery—6 cases.

VIII. Hypoplasia of the first portion of one anterior cerebral artery, and of the divisional branches of the basilar on both sides, both posterior cerebral arteries originating from the internal carotid stem—5 cases.

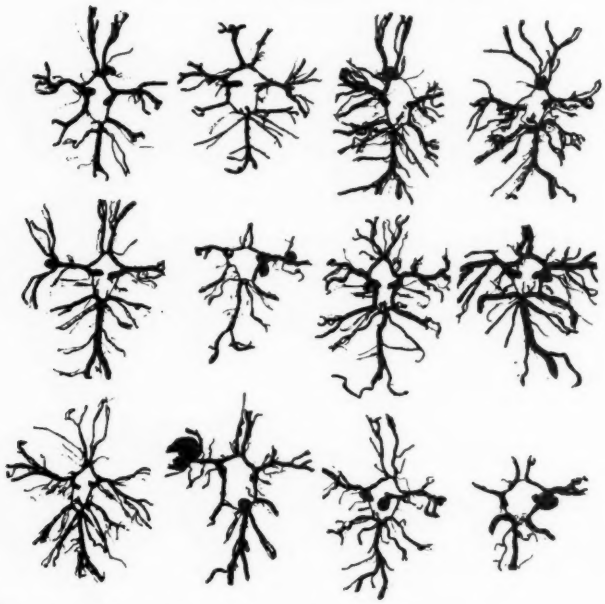

FIG. 3. Silhouettes of the cerebral vascular tree in ruptured aneurysm.

Top row (L–R)

1. Aneurysm of anterior cerebral at anterior communicating. Anterior Huebner from sac. Hypoplasia divisional branch basilar side opposite aneurysm. Posterior cerebral from internal carotid.
2. Aneurysm terminal bifurcation 2nd portion anterior cerebral. Second aneurysm bifurcation opposite middle cerebral artery. Hypoplasia one divisional branch of basilar; posterior cerebral from internal carotid.
3. Aneurysm anterior communicating artery. Recurrent artery of Huebner from sac. Extreme hypoplasia first portion one anterior cerebral artery, hypoplasia divisional branch basilar same side; posterior cerebral from internal carotid.
4. Aneurysm of anterior communicating artery. Hypoplasia first portion anterior cerebral and posterior communicating artery same side.

Middle row

5. Aneurysm bifurcation of middle cerebral. Normally formed circle.
6. Aneurysm internal carotid distal to posterior communicating. Second aneurysm bifurcation of middle cerebral artery same side. Hypoplastic circle of Willis with hypoplasia of divisional branches of basilar; posterior cerebral arteries from carotid stem.
7. Aneurysm internal carotid artery distal to posterior communicating. Anterior choroidal from sac. Hypoplasia divisional branches basilar; posterior cerebral arteries from internal carotid stems.
8. Aneurysm internal carotid at posterior communicating. Wide-necked sac. Hypoplasia anterior communicating and posterior communicating artery of one side. Hypoplasia one vertebral artery.

Bottom row

9. Two aneurysms of divisional branch basilar, proximal to junction of posterior communicating. Normally formed circle.
10. Large aneurysm of bifurcation of middle cerebral. Aneurysm bifurcation divisional branches basilar. Both divisional branches from sac. Hypoplasia of divisional branches; posterior cerebral arteries from internal carotid stem. Hypoplasia anterior communicating.
11. Aneurysm internal carotid proximal to posterior communicating. Aneurysm bifurcation of middle cerebral same side. Aneurysm opposite internal carotid, distal to posterior communicating. Anterior choroidal from sac. Normal circle of Willis.
12. Wide-necked aneurysm involving internal carotid and posterior communicating. Hypoplasia anterior communicating and one divisional branch basilar; posterior cerebral artery from internal carotid stem.

the component vessels, reversion to an embryonic stem of origin, or a combination of these factors. Eight basic patterns could be identified (Figs. 2 and 3).

No absolute correlation of aneurysms of a particular location with specific anomalous formation was found although 85 per cent of the 40 aneurysms of the anterior communicating artery were associated with hypoplasia of the first portion of one anterior cerebral, and the great majority of the aneurysms present lay in locations where circulation would be influenced by focal increase of resistance or altered field of supply.

DISCUSSION

The results of surgical treatment for intracerebral aneurysms are based admittedly on carefully selected cases,[1] particularly those in which focal signs, such as a third nerve palsy, precede any evidence of frank bleeding. The patients in our series represent an unselected cross section from a large general hospital and, with the exception of 6 patients, were admitted with signs indicative of intracranial bleeding. All aneurysms were located above the level of the sella. Even in selected cases, the best surgical results are obtained when the aneurysm is located at the carotid siphon. Surgical trapping in our cases would have been obviously dangerous because of the location of the aneurysm in reference to the production of permanent neurologic defects such as hemiplegia, and secondly, because of the difficulty in establishing adequate collateral circulation in an anomalously formed circle of Willis.

In such cases, a number of factors require thoughtful consideration before surgical therapy can be recommended. The general cardiovascular complications found frequently even in the younger age group are a potential source of danger, as is the presence of multiple aneurysms in approximately 20 per cent of cases.[1] Concomitant parenchymatous lesions in 94 also limit the possibilities of successful surgery since the prognosis is poorer in cases accompanied by intracerebral extension than in those in which the hemorrhage is confined to the subarachnoid space.[3]

SUMMARY

The patho-anatomic findings in a series of 143 cases of subarachnoid hemorrhage caused by leaking miliary aneurysms have been evaluated in relation to the potentialities for successful surgical intervention. All aneurysms lay above the carotid siphon; 129 originated from the internal carotid stems, and 14 from the basivertebral. Multiple aneurysms were present in approximately 20 per cent of the cases. Evidence of repeated bleeding, either ancient or recent, was present in most cases. Parenchymatous lesions were present in 94 cases, but hemorrhage accounted for only 29. Somatic disease, chiefly involving the cardiovascular system, complicated many cases. Anomalies of the circle of Willis were extremely common and of such a nature as to mitigate against adequate collateral circulation. Careful consideration of these factors is necessary in evaluating the potentialities of surgical therapy.

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INTRACRANIAL ANEURYSMS

II. SOME CLINICAL OBSERVATIONS CONCERNING THEIR DEVELOPMENT IN THE POSTERIOR CIRCLE OF WILLIS

ROBERT C. BASSETT, M.D., AND LLOYD J. LEMMEN, M.D.
Department of Surgery, University of Michigan Medical School and Hospital, Ann Arbor, Michigan

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IT IS general knowledge that most aneurysms of the cerebral circulation represent vestiges of the primitive circulatory system. A series of cases illustrating this point with reference to the anterior circle of Willis was presented in an earlier communication.[1] A similar consideration of the embryologic features of the basilar and vertebral systems correlated with the following 6 clinical observations with reference to the posterior Willisian circle further illustrates this point.

CASE REPORTS

Case 1. L.W. was a 36-year-old white male admitted on Dec. 15, 1951, with a 6-year history of hypertension. During this period he had had minor episodes of stiff neck associated with nausea, vomiting and occipital headaches. Seven days before admission he had onset of sudden severe occipital headache, nausea, vomiting, and stiff neck.

Examination revealed a B.P. of 200/118, pulse rate of 85 and marked nuchal rigidity without localizing signs. Lumbar puncture revealed grossly bloody spinal fluid.

On Jan. 2, 1952, while resting he became unconscious for 30 minutes and marked opisthotonos, headache and stiff neck developed. Four hours later he had sudden severe pain in the neck, became unconscious and expired.

At necropsy an aneurysm 4 mm. in diameter superior to the point of juncture of the basilar with the posterior cerebral arteries was disclosed (Fig. 1). The aneurysmal sac had perforated the floor of the 3rd ventricle and the point of rupture of the aneurysm was within the 3rd ventricle. All ventricles were dilated and contained clotted blood. Abundant hemorrhage beneath the inner meninges was present over the medulla and pons.

Case 2. R.R. was a 20-year-old white male admitted on May 18, 1952 with a history of having had rheumatic fever at the age of 10. In December 1951 a diagnosis of subacute bacterial endocarditis was made when scattered petechial hemorrhages developed with associated joint and muscle pain. Five weeks before admission he suffered a subarachnoid hemorrhage from which recovery was uneventful. On May 6, 1952 he had a recurrent hemorrhage with a 36-hour period of unconsciousness. The spinal fluid was grossly bloody.

Examination revealed a B.P. of 120/78, a pulse rate of 70 and marked nuchal rigidity. Tendon reflexes were hyperactive and the corneal reflex was decreased on the

FIG. 1. Aneurysm (arrow) above the confluence of the basilar artery with the posterior communicating arteries. Case 1.

right. Soon after admission a dilated right pupil and a right facial palsy developed. Respirations became Cheyne-Stokes in character and bradycardia developed.

Bilateral percutaneous carotid arteriography showed filling only of both distal anterior cerebral arteries. Left percutaneous vertebral arteriography revealed an aneurysm arising from the right superior cerebellar artery (Fig. 2).

The lesion was approached by a right temporal-occipital craniotomy and suboccipital craniectomy. The lateral sinus was divided and the tentorium was transected to the incisura. Firm adhesions were found between the aneurysmal sac and tentorium. A clip was placed on the superior cerebellar artery when the aneurysmal sac ruptured. The resultant hemorrhage was fatal.

Necropsy revealed the proximal remains of an aneurysm arising from the right superior cerebellar artery 1 cm. from its origin from the basilar artery. A congenital defect was present in the mitral valve; however, there was no evidence for vegetative heart disease.

FIG. 2. Vertebral angiogram (retouched) showing aneurysm of the right superior cerebellar artery. Case 2.

Case 3. L.H. was a 49-year-old white female admitted on Sept. 7, 1950 in a semiconscious state.

Examination revealed a B.P. of 250/100 and a pulse rate of 100, small fixed pupils, a left central facial palsy and hemiplegia, hypoactive reflexes and marked nuchal rigidity.

The patient expired shortly after admission.

Autopsy revealed a saccular dilatation of the anterior communicating artery, near the junction of the left anterior cerebral and anterior communicating arteries. A recent subarachnoid hemorrhage extended between the gyri and over the left hemisphere. Thick layers of clotted blood obscured the basilar vessels. *In many areas there was duplication of the basilar vessels with as many as four small vessels replacing the usual single basilar artery* (Fig. 4, No. 3).

Case 4. S.N. was a 19-year-old white female admitted on Oct. 4, 1950. In July, 1949 she first experienced vertigo associated with nausea and vomiting. One month later she had onset of unsteadiness and inability to maintain balance which progressed over a 6-month period when decreased sensation over the right side of the body and weakness of the right arm and leg appeared. Three months before admission diplopia, slurring of speech, increasing deafness in the left ear, and almost complete paralysis of the right arm and leg were noted. During the last 6 weeks she suffered daily headache, nausea and vomiting, the latter being aggravated by change in position.

Examination revealed a B.P. of 130/80, slurred speech, bilateral papilledema, weakness of the left medial rectus, nystagmus in all fields of regard, decreased sensory-motor function of the right trigeminal nerve, mild right central facial palsy, de-

creased hearing on the right, deviation of the uvula to the right, protrusion of the tongue to the left, impairment of all sensory modalities on the right, and a spastic right hemiparesis.

Ventriculography demonstrated symmetrical dilatation of the lateral ventricles. The posterior 3rd ventricle, aqueduct and 4th ventricle were not visualized.

On Oct. 11, 1950, a suboccipital craniectomy revealed a large tumor in the left cerebellopontine angle. The mass was incised and 25–30 cc. of old blood were evacuated.

Postoperatively, respiratory difficulty and hypertension developed and the patient expired.

Necropsy disclosed a greatly enlarged pons. The basilar artery was in the midline and the cranial nerves left the pons and medulla in normal fashion. Upon section, most of the pons was replaced by a circumscribed hemorrhagic mass 3 × 4 cm. extending its entire length. The lesion was more on the left than on the right, although it did extend into the right side (Fig. 4, No. 4). The gray and white matter at the ventral margin of the lesion showed normal pontine configuration. *Microscopic section revealed an aneurysm composed of a thin connective-tissue wall surrounded by multiple malformed vascular channels.* The surrounding pons showed a combination of hemorrhagic and ischemic liquefaction necrosis.

Case 5. W.B. was a 46-year-old male admitted on Feb. 28, 1949. For 1 year he had had generalized headaches. Three days before admission severe occipital headache developed, followed by stiff neck. Two days before admission he had a severe generalized convulsion and became comatose.

Examination revealed a B.P. of 165/98 and a pulse rate of 82. He was comatose, but responded to painful stimuli with spontaneous movements of the arms. Nuchal rigidity was present. The pupils were round and equal and reacted to light. There was an incomplete right 3rd nerve palsy. He had bilateral papilledema with severe hemorrhagic retinopathy and a bilateral extensor plantar response. Lumbar puncture revealed a pressure above 550 mm. of water. The fluid was grossly bloody.

The patient expired shortly following admission.

Necropsy disclosed a large right vertebral arterial aneurysm approximately 2 cm. proximal to the junction of the right and left vertebral arteries to form the basilar artery (Fig. 4, No. 5). This aneurysm measured 1 × 0.5 cm. with a point of rupture approximately 8 mm. in length. The entire base of the skull was filled with fresh blood in the subdural space. The ventral surface of the brain revealed a marked degree of subarachnoid hemorrhage, particularly in the cisternae pontis and interpeduncularis. The usual anatomical pattern of the circle of Willis was noted back to the point where the basilar artery joined the two posterior communicating arteries. *From this point caudad, the basilar artery swung widely to the right margin of the pons and again returned to the midline at the vertebral confluence.* The left pontine arteries were much larger than the right and traversed the pons to enter that structure along the left border. The right pontine arteries were relatively short and appeared to extend directly from the basilar artery into the right side of the pons.

Case 6. L.D. was a 34-year-old colored female who had been well until July 2, 1950, when severe right frontal headache suddenly developed. She went to bed for 2 hours and when she arose her gait was unsteady and she staggered as she walked. On looking into a mirror she noted that her right eyelid drooped and that her mouth was out of shape. She was unable to drink water. She returned to bed and slept until the

next morning. Upon attempting to walk the patient noticed that her gait was still unsteady and that everything seemed to whirl in front of her.

The B.P. was 120/80, pulse rate 80 and respiratory rate 20. There was severe nystagmus in all fields of regard, with ptosis of the right eyelid. Pupils were small, fixed, and unequal, the left being the larger. There was hyperesthesia over the right side of the face, and the right corneal reflex was absent. A peripheral facial palsy was present on the right with taste diminished on the right. There was mild weakness in turning of the head to the left and marked deviation of the protruded tongue to the right. Superficial pain was decreased over the left half of the body. The finger to nose test was performed poorly on the right. The patient walked only with assistance in a very ataxic fashion. Sweating was absent over the left half of the body. Meningeal signs were absent. Blood serology was normal; she refused lumbar puncture.

During her hospitalization there was progressive improvement and at the time of her discharge on July 29, 1950, only minimal residuals remained.

The patient was seen on several occasions in the out-patient clinic, showing improvement with each visit. She was last seen on Jan. 29, 1952, and was walking without difficulty. The corneal reflex was absent on the right and a residual numbness was present on the right side of her face. The numbness of the left side of the body was not apparent.

On March 3, 1952, she was found unconscious in her bed. She had been re-admitted to the hospital because of headache and pain in her legs which had been present for several days.

Examination revealed a B.P. of 85/70, pulse rate of 120, and respiratory rate of 34. The eyes were rotated down and out. There were numerous superficial retinal

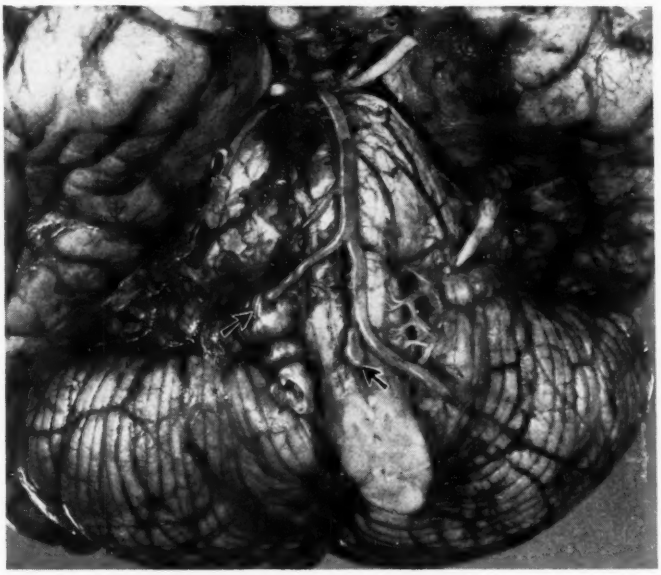

FIG. 3. Three serial globular aneurysms of the right vertebral artery with the hypoglossal nerve exiting at the most rostral border (upper arrow) and a single aneurysm (lower arrow) of the anterior spinal artery.

hemorrhages and subhyaloid hemorrhages bilaterally. The left pupil was larger than the right. Nuchal rigidity and marked rigidity of all muscles were present. Spinal fluid pressure measured 25 mm. of water and was grossly bloody.

The patient remained unconscious until death on Mar. 31, 1952.

Necropsy revealed *three serial globular aneurysms of the right vertebral artery,* with the hypoglossal nerve exiting at its most rostral border (Fig. 3). *A single aneurysm was found on the anterior spinal artery near its junction with the left vertebral artery.*

DISCUSSION

Padget's[3] description of the normal development of the cranial arteries in the human embryo makes more comprehensible these anomalies of the adult cerebral vascular tree. Her studies have shown that in the 4 mm. embryo the internal carotid artery produces a posterior division (later remaining as the posterior communicating artery) which joins the two longitudinal neural arteries ventral to the neural tube. As early as the 4 mm. stage in development, the emergence of the bilateral longitudinal neural arteries precedes the formation of the basilar artery. These long vessels be-

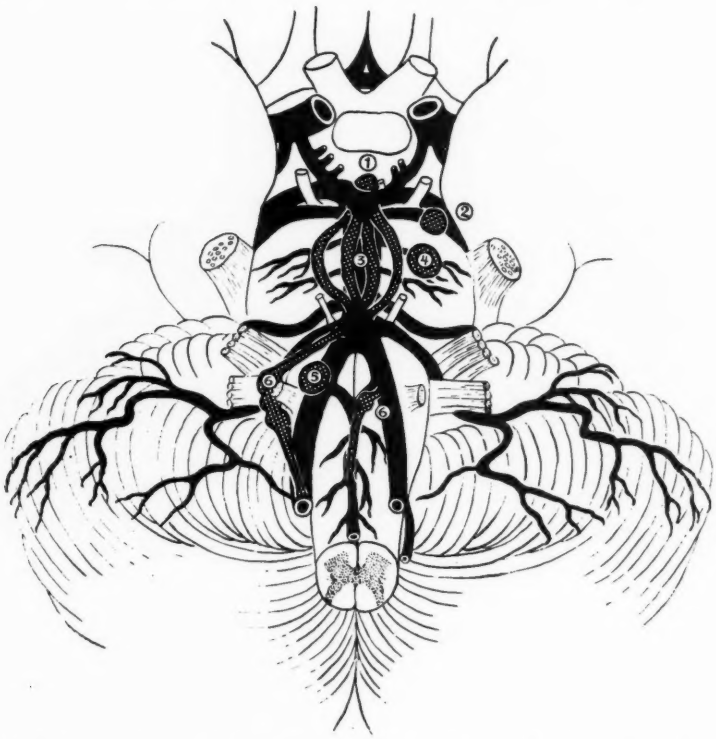

FIG. 4. Diagram of the normal adult arterial pattern with the anomalies discussed superimposed (shaded) and identified by case numbers.

come one by capillary fusion during the 5–8 mm. stage. As growth proceeds the islands of primitive circulatory channels formed in this fashion disappear, leaving the fused midline basilar artery as seen in the more mature embryo. Error in normal fusion and absorption of the bilateral neural arteries at this early stage in development therefore may result in the residual aneurysm seen at the juncture of the basilar artery with the posterior cerebral arteries (Figs. 4–5). An exactly similar defect was described in a human embryo of 12 weeks by Bremer.[2]

Some break in rhythm of the normal dynamics responsible for development of a single basilar artery can similarly account for the multiple basilar arterial channels seen in Case 3 and the laterally placed basilar artery in Case 5 which represents a perpetuation of the embryonic right longitudinal neural artery. The superior cerebellar artery emerges from the cranial end of the embryonic basilar artery in the 9 mm. stage of development. Failure of absorption of primitive circulatory components forming the cephalad portion of the basilar artery might therefore account for the aneurysm of the superior cerebellar artery in Case 2.

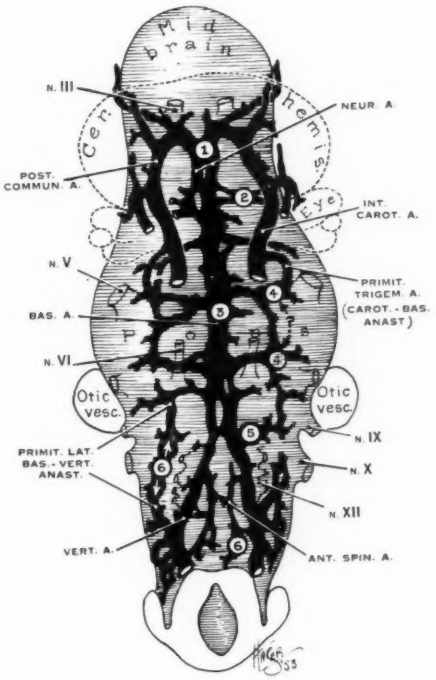

FIG. 5. Composite diagrammatic reconstruction of the circulation of 4 mm., 5.3 mm., 5.5 mm., 9 mm., and 12.5 mm. embryos (after Padget) with sources for the lesions discussed identified by numerals corresponding to each case.

During the 4–5 mm. stage the bilateral longitudinal neural arteries are reinforced by remnants of two highly transitory presegmental branches of the paired aortae, namely, the primitive otic artery, at the level of the acoustic nerve and the otocyst, and the primitive hypoglossal artery, in the region of the 12th nerve. Embryonic residuals of this latter vessel on the longitudinal artery (which later forms the vertebral artery) could account for the aneurysm demonstrated in Case 5.

This explanation for the aneurysmal lesion seen in Case 4 is more difficult as it arose in close proximity to the site of the former otic artery where the lateral branches of the bilateral longitudinal neural artery join the primitive lateral basilar-vertebral anastomosis. This lateral channel paralleling the bilateral longitudinal neural artery is fed by lateral branches of

the basilar artery and caudally by the first cervical segmental vessels and constitutes an accessory basilovertebral anastomosis during the formation of the vertebral artery from the upper cervical segmental arteries.

A more acceptable explanation on the basis of frequency of occurrence is that this lesion represents a residual of the primitive trigeminal artery which, according to Padget,[4] is more apt to persist. Errors in resorption of these primitive channels with retention of remnants of this lateral basilar-vertebral anastomosis may be interpreted as the mechanism for the development of the serial aneurysmal dilatations seen in Case 6. Medial to the developing vertebral artery, the originally paired bilateral longitudinal channels form the adult anterior spinal artery. The single aneurysm of the anterior spinal artery in Case 6 must therefore represent an error in fusion and absorption of these primitive channels.

SUMMARY

Six cases presenting aneurysmal residuals and abnormal vascular patterns of the posterior circle of Willis are presented with a brief discussion of the embryologic factors concerned in the development of this structure as an interpretation of the origin of the pathologic anatomy.

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CONTROLLED HYPOTENSION

II. A PRELIMINARY REPORT ON "ARFONAD"® (RO 2-2222)*

MAX S. SADOVE, M.D., GORDON M. WYANT, M.D., GWEN GLEAVE, M.D., AND PAUL C. BUCY, M.D.

Departments of Surgery (Anesthesiology), Neurology and Neurological Surgery, University of Illinois College of Medicine, the Veterans Administration Hospital, Hines, Illinois, and the Chicago Memorial Hospital, Chicago, Illinois

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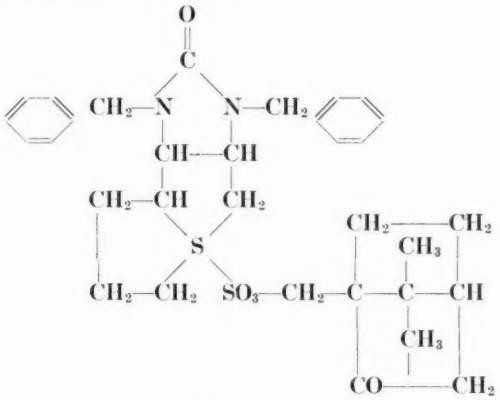
In a previous communication[3] we discussed the subject of induced hypotension for surgical operations, and in particular as it affects the field of neurosurgery. We placed special emphasis on the methonium compounds which then represented the latest means of obtaining a lowered blood pressure during surgical operations. We pointed out in our paper the advantages of this method over previous attempts at controlled hypotension, but we also mentioned the definite limitations and disadvantages of the methonium compounds. Among these are the large individual variations in response to the drug and in the amount of the drug that is required, the uncertainty of obtaining adequate hypotension with the agent, and the occasional occurrence of marked diminution of response to subsequent doses. Also, hypotension tends to be fixed at a certain level rather than be flexible in response to variations in the dose. In essence then, the limitations of the methonium drugs consist in a certain unpredictability of action. In addition, once adequate hypotension is obtained, it can be reversed only either by elimination or destruction of the drug, or the hypotension may be counteracted by a vasopressor. Further hypotension then becomes practically impossible until the effect of the vasopressor has been dissipated. The elimination or destruction of the drug requires time, and even if the blood pressure returns to normal levels, patients remain vasolabile for a period of hours up to two days. Nevertheless the methonium drugs have their uses, although they are not the perfect solution to the problem of controlled hypotension for surgical procedures. Any agent that is capable of altering blood pressure gradually to any desired level and that would permit this level to be altered both in an upward and downward direction on a minute-to-minute basis would represent a decided advantage over the methonium compounds. Such an agent seems to be available in "Arfonad" (RO 2–2222). It has been used by us in 62 cases with satisfactory results in most instances.

* Supplies of Arfonad (RO 2–2222) have been generously donated by Hoffmann-LaRoche, Inc. through the courtesy of E. L. Sevringhaus, M.D. and M. J. Schiffrin, Ph.D.

Published with approval of the Chief Medical Director, Veterans Administration. Statements and conclusions published by the authors are the result of their own studies and do not necessarily reflect the opinion or policy of the Veterans Administration.

PHARMACOLOGY

Arfonad is a thiophanium derivative with the formula:—d-3,4(1′,3′-dibenzyl-2′-keto-imidazolido)-1,2-trimethylene thiophanium d-camphor sulphonate. The structural formula is:



It is capable of reducing arterial blood pressure in anesthetized animals and in man. The hypotension is in part produced by sympathetic ganglionic blockade which causes metarteriolar dilatation. The part played by reduced cardiac output and possibly by other mechanisms is as yet undetermined. Vasodilatation is responsible for pooling of blood in the periphery of the body, and this in turn causes reduction of venous return to the heart and consequently decrease of cardiac output. The vasodilatation also causes marked diminution of peripheral resistance, and this decreased resistance far outweighs the reduction in cardiac output; in consequence the over-all workload of the heart is reduced. This fact first led to the use of Arfonad in the treatment of pulmonary edema of cardiac origin by Sarnoff and Goodale, who also reported on its use for hypotension in four neurosurgical procedures.[5]

According to Randall, Peterson and Lehmann[2] the acute toxicity of Arfonad varies greatly with the route of administration and the species of animals employed. Ephedrine, epinephrine, and similar vasopressors will abolish the vasodepressor effects of Arfonad; Arfonad is ineffective on arterial pressure during the pressor response to these drugs. In dogs, but not in man, histamine release has been demonstrated after the administration of Arfonad.[1]

There is suggestive evidence that sympathetic ganglionic blockade is only one of the factors involved in the production of hypotension with Arfonad. Although no histamine release has as yet been demonstrated in man, it is conceivable that this may be one of the other mechanisms. From work carried out on ourselves and on volunteers[4] we have been able to draw the following conclusions: After administration of the drug to conscious,

unpremedicated man, a slight fall in blood pressure is produced which tends to level off to a plateau where the pressure persists, despite further administration of Arfonad in rather large doses. This level is in the neighborhood of 90 mm. Hg systolic in the conscious individual with normal blood pressure. This fact may indicate that the autonomic blockade is not complete. After administration of the drug conscious individuals lose their normal vasomotor responses and are unable to compensate for changes in position. Thus, when the head is elevated, a further fall of blood pressure can be obtained which will again level off to a plateau despite the administration of more Arfonad. These persons respond to oxygen deficiency with a tachycardia and to an excess of carbon dioxide with hyperpnea and a tendency of the blood pressure to rise again. In the unanesthetized human being the venous pressure remains essentially unchanged, as do electrocardiographic and electroencephalographic tracings. Plethysmographic recordings demonstrate an increase in peripheral pulse volume, as would be expected from the arteriolar dilatation that the drug produces. Ballistographic studies of cardiac output indicate that the stroke volume of the heart is reduced by 5 to 10 c. mm. The minute volume is not markedly altered because of compensatory changes in cardiac rate. These studies are still in progress and our conclusions, although suggestive, are not definite.

Clinically, in the anesthetized patient, any degree of hypotension can be produced. With extreme hypotension the venous pressure tends to fall, otherwise it remains near normal, and venous bleeding will continue, the degree depending upon the posture of the patient and the dependency of the bleeding point. Despite normal venous pressure, engorgement or dilatation of peripheral veins is often present. There is no direct relation between these two factors, as a greater degree of relaxation of a vein renders it more prominent, while the actual pressure within the vein, as measured manometrically, may remain essentially unchanged. The fall of blood pressure develops slowly over a matter of minutes and is readily controllable. It reverses itself when the administration of Arfonad is slowed or discontinued. There is thus a minute-to-minute controllability of the degree of hypotension. However, there still remains a marked difference in the dose required by different patients. Also, the more profound the anesthesia, the smaller the dose of Arfonad that will be needed. Clinically, we have observed no side-action that caused alarm; occasionally an atropine-like effect can be observed, as indicated by mydriasis, a flushing of the skin, conjunctival injection, and a dry mouth. Nothing is known to date regarding the fate of Arfonad in the body nor of its avenue of elimination. The rapidity with which the effect of the drug disappears, however, would suggest that it is metabolized in the body.

CLINICAL APPLICATION

Arfonad is administered as an intravenous injection in a 0.1 per cent solution in 5 per cent dextrose in water. A separate injection is used for this purpose, so that blood and fluid replacement will not interfere with the main-

tenance of the hypotensive state. Administration of Arfonad is started before the incision is made at an approximate rate of 40 to 60 drops per minute. In this manner it is possible to slowly lower the pressure over a period of 10 to 15 minutes. This is most desirable because the cardiovascular system is enabled to gradually re-establish an equilibrium between venous return and cardiac output. Thereafter the rate is adjusted in such a way that satisfactory conditions for the operation obtain. We have no preconceived idea as to the blood pressure level to be attained. Each patient responds in a different way

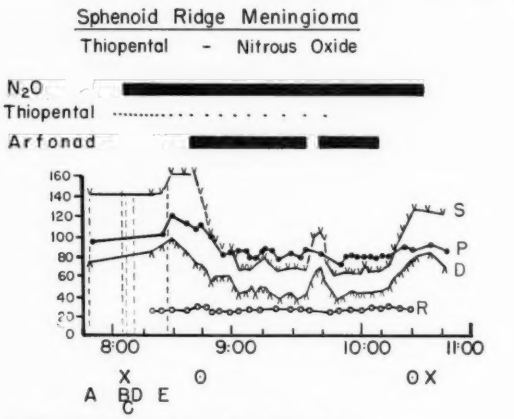


FIG. 1. *Removal of meningioma from sphenoid ridge.* Early pressure response to local infiltration of scalp (E). Good hypotension obtained with pulse rate at 80 throughout period of lowered blood pressure. Note prompt rise of blood pressure during short discontinuance of injection at 9:45 a.m. and new fall when Arfonad administration was resumed. Only 500 cc. of blood required during entire operation. (DTC = d-tubocurarine chloride; S = systolic arterial pressure; D = diastolic pressure; P = pulse rate; R = respiratory rate.)

to different amounts of the drug. In normotensive patients a systolic blood pressure of 70 to 80 mm. Hg would seem a safe level from which to start. Thereafter we are guided by the need of the surgeon for more or less hypotension. Blood pressure is kept at the highest level compatible with the surgical maneuver at hand at any particular moment. This is possible because changes in blood presssure, when required, can be effected rapidly by simply altering the rate of flow of the Arfonad injection. There is usually a critical level of blood pressure above which bleeding is almost normal; this critical point is often well below the normal arterial pressure.

The safe level for hypotension must be assessed for each individual patient. A blood pressure reading that is safe for one may not be safe for an-

other. By the same token, operating conditions may be good in one case, poor in the other, despite identical blood pressure levels. The patient must be watched closely throughout the procedure for such signs of danger as tachycardia, airhunger, perspiration, increased capillary refill time, pallor, venous constriction, and other signs of incipient peripheral circulatory failure. Ideally, blood should be replaced as it is lost. However, in many cases when the operation is performed under controlled hypotension, the blood loss is minimal, so that it is safe to maintain the circulating volume with crystalloid solutions. One must always bear in mind that individuals who have been rendered hypotensive in this fashion are particularly vulnerable to

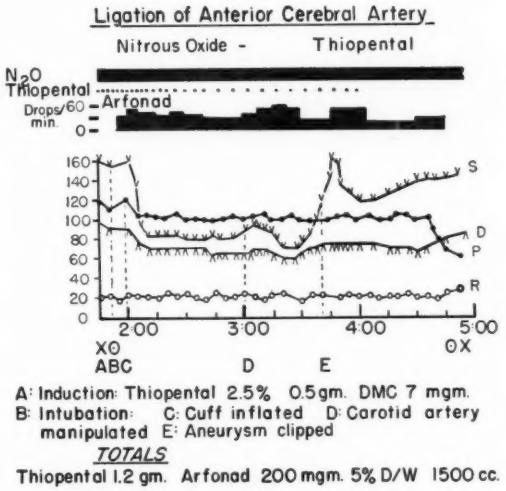


FIG. 2. *Ligation of anterior cerebral artery.* Good hypotension with marked narrowing of pulse pressure and unchanged pulse rate. (DMC = dimethyl-tubocurarine iodide.)

any considerable loss of blood. Their mechanisms of compensation for blood loss have been impaired. The effects of such loss may, therefore, be greatly exaggerated as compared with normal individuals.

As has been stressed in our previous paper, we keep our patients horizontal and do not elevate the head lest dangerous cerebral ischemia develop. We are aware that some others who use induced hypotension do not regard this precaution as essential. The blood pressure is allowed to return to normal levels slowly, by discontinuing the Arfonad gradually, before the wound is closed. Such a reversal of hypotension takes place spontaneously in most cases in a matter of minutes after the injection of Arfonad has been decreased or discontinued. It is important that hemostasis with a normal arterial tension be assured before the wound is closed. Should vasopressors be indicated, the dose of such vasopressors must be kept extremely small. The usual doses may cause a dangerous rise of blood pressure.

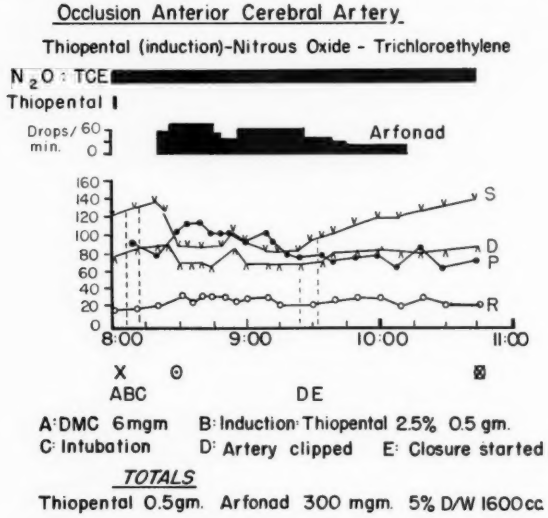


FIG. 3. *Occlusion of anterior cerebral artery.* Slow rise of blood pressure in response to gradual diminution of rate of injection of Arfonad. Clipping of artery is not attended by a pressure response, because of somewhat greater depth of anesthesia (nitrous oxide-trichloroethylene), as compared with that in Fig. 2. (TCE = trichloroethylene.)

INDICATIONS AND CONTRA-INDICATIONS

Arfonad is used whenever any of the other forms of induced hypotension would be indicated, particularly in patients with intracranial aneurysms, arteriovenous anomalies or very vascular tumors. Exposure is often improved during hypotension which renders the brain less voluminous and more compressible, although this fact of itself is not sufficient indication for the use of any form of induced hypotension.

Contra-indications are also similar to those for the methonium compounds. They include severe liver disease, arteriosclerosis, degenerative or vascular heart disease, shock, and inadequate blood volume from any cause. It must also be clearly understood that Arfonad is still in the investigative stage.

COMPLICATIONS

Three patients had postoperative complications for which the hypotensive technique may or may not have been responsible or in which it may have been a contributing factor.

Case 1. Right frontal craniotomy, subtemporal decompression and biopsy of intracranial tumor in a 43-year-old male under thiopental (sodium pentothal®)-nitrous oxide anesthesia. He expired the following day without having regained consciousness. Autopsy showed hemorrhage into the tumor site. This was one of the earlier cases in the series, and the Arfonad infusion was not discontinued until the

end of the operation. If the blood pressure had been allowed to rise before the wound was closed, it is possible that this complication may have been avoided. The surgeons were of the opinion that the outcome in this case was not related to hypotensive anesthesia.

Case 2. Hemiglossectomy, mandiblectomy, and radial neck dissection in a 59-year-old male under Rapital®-cyclopropane-ether-nitrous oxide sequence. Hypotension was induced for 25 minutes during this 3-hour operation. Exactly 24 hours after conclusion of the operation, the patient suffered a cerebrovascular accident with engorgement of the eyegrounds and aphasia. His condition improved and he was eventually discharged from the hospital. Although the hypotension may have been a contributing factor in this case, it should be noted that the operation included the ligation of the external carotid artery and all jugular veins on the side of operation, and that the very extensive dissection included the opening of numerous and large vascular channels.

Case 3. Excision of large tumor from left side of neck in a 36-year-old male under thiopental-nitrous oxide anesthesia. Liver failure developed postoperatively, but the patient eventually recovered. Tests prior to operation showed marked impairment of liver function, but these reports were not available in his chart at the time of operation. Had these findings been known, hypotension would not have been used. This case was clearly one in which induced hypotension should not have been used.

In Cases 1 and 3 an error of judgment was committed, although it seems doubtful that hypotension was a major factor in the causation of the complication. In Case 2 it is possible that the hypotension was a factor, although the site and extent of operation may have been the real causes. None of these patients was operated upon by any of the present authors.

DISCUSSION AND CONCLUSIONS

Arfonad, in our opinion, is a decided improvement over the methonium compounds, in that it allows for a slow and gradual lowering of blood pressure as well as minute-to-minute control. It is therefore possible to adjust the degree of hypotension to the need of the surgeon from one moment to the next. This type of hypotension is thus truly "controlled," as opposed to the previously described methods.

This is not a technique for the novice or occasional anesthetist; neither is the method recommended for indiscriminate use. The agent is still in the experimental stage and indications should therefore be limited to operations in which the patient will decidedly benefit from it; either those procedures that could not be done without it, or when the dangers would be much greater in operating with normal blood pressure than under controlled hypotension.

It is our personal impression and that of the surgeons who have operated on patients under controlled hypotension, that these patients are in a far better general condition after the operation than one would expect after a similar operation without it. A much larger clinical experience and more detailed pharmacological data in man are needed before it will be possible to

assign to Arfonad a permanent place and to determine the exact indications for its use.

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TRANSVENTRICULAR WOUNDS OF THE BRAIN*

MAJOR GORDON T. WANNAMAKER, M.C., U.S.A.†
Section of Neurological Surgery, Tokyo Army Hospital, Tokyo, Japan

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THIS report is based on 105 consecutive Korean battle casualties of surgically verified transventricular wounds of the brain treated at Tokyo Army Hospital from September 1950 through March 1952.‡ The over-all mortality rate was 10.47 per cent. The value of early definitive neurosurgery is brought out by a comparison of the operative results before and after the establishment of an organized neurosurgical team in Korea in February 1951.

DEFINITION AND DIAGNOSIS

Wounds of the ventricle in this series were produced by missiles or foreign bodies passing through or into the ventricular system. Actual visualization of the opening into the ventricle at surgery was the basis for diagnosis. There was no definite clinical syndrome characteristic of transventricular wounds even though most of the patients had high temperatures and stiff necks. The physical findings depended upon the area of the brain involved. A diagnosis of ventricular penetration was suspected when x-ray films showed evidence of the missile canal, outlined by bone fragments, passing through the position normally occupied by the ventricles. The lateral ventricles were most frequently involved, accounting for all cases except 3 in which the 3rd ventricle was penetrated. There were no cases of penetration of the 4th ventricle.

NEUROSURGICAL ORGANIZATION

Before going into the statistical analyses of these cases, it is advisable to give a picture of the over-all neurosurgical organization in the Army during the progressive stages of the Korean campaign covered in this report. During July and August 1950 no accurate records were kept. From September 1950–February 1951, the Neurosurgical Service at Tokyo Army Hospital was the only Army Neurosurgical Center in the Far East Command. In February 1951, a neurosurgical team was established in Korea and func-

* Presented at the sixth annual meeting of the Southern Neurosurgical Society, Baltimore, Maryland, January 29, 1954.

† Present address: Brain Tumor Registry, Yale University School of Medicine, New Haven, Connecticut.

‡ The following officers were associated with the author in the care of the casualties on which this report is based: Lt. Col. Arnold M. Meirowsky, M.C., Neurosurgical Consultant, Far East Command, Samuel W. Atkins, Joseph C. Barnett, Edward J. Bishop, Robert A. Clark, Philip R. Dodge, Griffith R. Harsh III, George J. Hayes, Milan Leavens, John B. Moyer, Jose Ninecurt, Richard R. Patterson, and Paul R. Rosenbluth.

tioned at the level of an Evacuation Hospital. With the arrival of additional personnel, a mobile neurosurgical team was established in Korea in October 1951 at the level of a Mobile Army Surgical Hospital. From September 1950 the entire personnel was under the direction of Lt. Col. A.M. Meirowsky,[4] Neurosurgical Consultant of the Far East Command. All doctors received an initial period of instruction at the Center at Tokyo Army Hospital. Records of all patients evacuated from the neurosurgical teams in Korea and of all patients admitted to the Tokyo Army Hospital Center were maintained. From the onset the Center served as the second echelon of treatment. All Army neurosurgical casualties, many Marines, Air Force, and United Nations personnel were included in the series. The fact that this report is based mostly on the results of the second echelon of treatment no doubt contributes to our low mortality rate. For this, allowance must be given. As the late Sir Hugh Cairns[3] stated, "The farther from the front the better the mortality statistics."

STATISTICAL ANALYSIS

The 105 consecutive casualties here reported were treated on the Neurosurgical Service, Tokyo Army Hospital, during the period of September 1950 through March 1952. Only 10 of these patients with transventricular wounds had not undergone prior surgery. Before the establishment of a neurosurgical team in Korea in February 1951, the majority of the patients were operated upon at various installations in Korea and Japan, frequently without the benefit of a neurosurgeon. The value of early definitive neurosurgery was

TABLE 1

	No. Cases	Infected on Admission	No Prior Surgery	Initial Surg. or Re-op. TAH	Over-all Mortality
Group I: Sept. 50–Feb. 51	32	17 (53%)	9	31	8 (25.00%)
Group II: Mar. 51–Mar. 52	73	11 (15%)	1	22	3 (4.11%)
Total	105	28 (26.6%)	10	53	11 (10.47%)

again demonstrated. As Eden[8] aptly put it, "The surgeon who first operates on an open brain wound, makes or mars it. There is no first aid operation. Ideally the initial operation should be the final and complete one. Failure to obtain primary closure or inadequate removal of indriven bone fragments frequently spelled a vicious circle of cerebral fungus, brain abscess and meningitis."

In 17 (53 per cent) of the 32 patients admitted to Tokyo Army Hospital prior to the establishment of an Army neurosurgical team in Korea (Group I, Table 1), there was evidence of meningitis or brain abscess. Of the 32 patients, 31 required reoperation for the causes shown in Table 2.

Of the 73 patients admitted from March 1951 to March 1952 (Group II

TABLE 2

Indication for Surgery—TAH	Group I	Group II
Retained bone fragments	9	10
Brain abscess—requiring open treatment	4	3
Cerebral fungus present on admission	5	3
CSF fistula at site of wound closure	1	3
Persistent neurological deficit	1	1
Subcortical clots	2	0
Large metallic foreign body—mobile	0	1
No prior surgery	9	1
Total	31	22

Table 1), 51 did not require any further surgery. The remaining 22 were reoperated on for the causes shown in Table 2.

A comparison of the two groups shows that the incidence of infection and the rate of mortality declined sharply after the establishment of a trained neurosurgical team near the Korean battle line, even though there were several patients with transventricular wounds eventually evacuated to Japan who had received initial treatment at installations other than the Army neurosurgical team. The incidence of infection at time of admission to Tokyo Army Hospital dropped from 53 per cent in Group I to 15 per cent in Group II. The over-all mortality in Group I, before the establishment of the team, was 25.0 per cent, and in Group II it was 4.11 per cent. This marked difference was no doubt the result of early definitive debridement (Table 3), adequate antibiotic therapy, and vigorous postoperative management with early removal of retained bone fragments to prevent abscess formation. It has been shown that, as in infections in other parts of the body, the earlier the initial complete debridement, the lower the postoperative infection rate.[7,19] Penicillin and streptomycin were used routinely in practically all cases in Korea. Culture and sensitivity tests became readily available at Tokyo Army Hospital in January 1951. It was then possible to identify within a 24–36 hour period the type of organism involved and to administer the specific antibiotic indicated. Practically all patients who were infected on admission to Tokyo Army Hospital had organisms

TABLE 3

	No. Cases	Time Lag from Injury to Surgery (Average)
Group I: Sept. 50–Feb. 51	32	44.1 hours
Group II: Mar. 51–Mar. 52	73	24.6 hours*
Total	105	30.7 hours
Shortest		3 hours
Longest		15 days

* The majority of operations at the mobile teams were performed within 12 hours of injury. However, because of the tactical situation, a few patients were delayed in evacuation to the teams, bringing up the over-all average.

that were resistant to penicillin and streptomycin. The availability of aureomycin, terramycin, and chloromycetin, no doubt, saved many patients with ventriculitis and meningitis who would have died. The goal of a high percentage of recoveries from penetrating wounds of the brain as anticipated by Cushing[6] in 1918, with early definitive surgery and appropriate antibiotics, is now within the realm of achievement.

TREATMENT

An over-all analysis of over 600 consecutive penetrating wounds of the brain treated during the same period of this report, showed that the patients with ventricular wounds were the sickest and carried the highest mortality incidence. This fact has been brought out in previous reports by Cushing,[5] Schwartz,[20,21] Haynes[10,11] and others.[1,16,22]

Pre-operative. The pre-operative management of penetrating wounds of the head has been adequately described elsewhere and will not be detailed here. Emphasis again must be placed upon the importance of pre-operative x-rays, preferably stereoscopic views, with accurate localization of intracranial bone fragments and foreign bodies. However, with present field equipment requiring long exposure time, this was practically impossible at the advance units.

Operative. The principles of radical debridement of the brain with removal of devitalized cerebral tissue, clots, bone fragments, pieces of helmet lining, hair, dirt, etc., have been all established.[1,4,9,12,16,21–23] The metallic foreign body (missile) is removed, if it can be readily reached without further destruction of vital areas of the brain. Superficial metallic fragments near the cortical surface of the brain at a site distant to the point of penetration are occasionally associated with hematoma. In this series there has been only 1 case of complication resulting from a retained metallic foreign body. This was quite large and moved about within the missile canal, causing further brain damage. It was subsequently removed.

The open method of debridement through an adequate craniectomy with direct visualization of the missile tract as used by Schwartz,[21] Webster,[24] and others, was the method used in this series. Pentothal sodium induction with endotracheal nitrous oxide-oxygen anesthesia was employed routinely in this series. There were no deaths or complications from the anesthesia, which was maintained in a light plane. The scalp, muscles, and pericranium were adequately debrided. It was necessary to perform a craniectomy of such size as to allow for debridement of the dura mater and superficial cortical tissue as well as visualization of the missile canal. A craniectomy of 4–5 cm. in diameter was usually found to be the minimum that could be used. Silver clips were the method of choice for obtaining hemostasis of cortical vessels. The cautery was used sparingly, as it was felt that otherwise more extensive thrombosis and necrosis resulted. No unusual foreign body reaction was noted about the silver clips in patients subsequently re-operated upon. The softened walls of the missile canal were removed by suction. The canal was inspected with a Frazier lighted retractor and gently palpated for for-

TABLE 4A

Bacteriological survey with culture and sensitivity reports prior to establishing neurosurgical team in Korea

September 1950–February 1951

	Name	Source of Culture	Organism	Sensitivity					Recovery
				Pen	Strep	Chloro	Aureo	Terr	
1	C.E.	Brain fungus	No record	Unknown					+
2	D.B.	Brain abscess	No record	Unknown					+
3	L.C.	Brain abscess	Pseudomonas aeruginosa	Unknown					0
		Spinal fluid	Clostridium perfringens						
			Clostridium putrificum						
			Clostridium tetani						
4	J.H.	Spinal fluid	Pseudomonas aeruginosa	Unknown					0
5	R.M.	Brain abscess	Aerobacter aerogenes	0	0	?	?	?	0
			Hemolytic streptococcus	?	?	?	?	?	
			Escherichia coli	?	+	?	?	?	
6	W.T.	Spinal fluid	+ cocci on smear	Unknown					0
		Brain abscess	+ cocci on smear	Unknown					
7	A.B.	Brain abscess	Staphylococcus	0	+	?	+	?	0
		Spinal fluid	Sterile						
8	G.R.	Fungus	Hemolytic staphylococcus	+	+	0	0	0	+
			Pseudomonas aeruginosa	0	0	0	0	0	
		Spinal fluid	Alcaligenes faecalis	0	0	+	+	+	
9	G.B.	Epidural	Hemolytic staphylococcus	0	0	+	+	+	+
		Brain abscess	Hemolytic staphylococcus	0	0	+	+	+	
10	D.M.	Flap tap	Hemolytic staphylococcus	0	0	+	0	0	+
		Spinal fluid	Hemolytic staphylococcus	0	0	+	0	0	
11	S.W.	Spinal fluid	Hemolytic staphylococcus	+	0	+	0	0	+
12	J.R.	Spinal fluid	Pseudomonas aeruginosa	0	sl.	sl.	0	sl.	+
			Hemolytic streptococcus	0	0	+	0	0	
			Hemolytic staphylococcus	0	0	+	+	+	
			Alcaligenes faecalis	0	0	+	+	+	
		Flap tap	Pseudomonas aeruginosa	0	0	0	0	0	
13	J.Q.	Brain abscess	Gram+cocci in pair and short chain on smear, sterile culture						+
14	R.T.	Spinal fluid	Pseudomonas aeruginosa	0	0	sl.	0	0	+
		Brain abscess	Pseudomonas aeruginosa	0	0	sl.	0	0	
		Subgaleal	Pseudomonas aeruginosa	0	0	sl.	0	0	
15	T.L.	Subgaleal	Hemolytic staphylococcus	0	0	+	0	0	+
			Gamma streptococcus	0	0	+	0	0	
		Brain	Gamma streptococcus	0	0	+	0	0	
		Spinal fluid	Nonhemolytic staphylococcus	Unknown					
			Bacillus subtilis	Unknown					
			Gamma streptococcus	Unknown					
16	R.M.	Epidural	Hemolytic staphylococcus	0	0	+	+	+	0
		Spinal fluid	Alcaligenes faecalis	0	0	+	+	0	
		Brain	Aerobacter aerogenes	0	0	+	0	+	
			Alpha streptococcus	0	0	+	0	+	
17	E.D.	Subgaleal	Hemolytic staphylococcus	+	+	+	+	+	+
		Brain abscess	Hemolytic staphylococcus	0	0	+	+	+	
			Bacillus subtilis	+	+	+	+	+	
			Hemolytic staphylococcus	0	+	+	+	+	
		Spinal fluid	Hemolytic staphylococcus	0	+	+	+	+	

Pen = Penicillin
Strep = Streptomycin
Chloro = Chloromycetin
Aureo = Aureomycin
Terr = Terramycin
sl. = slight

TABLE 4B

Bacteriological survey with culture and sensitivity reports after establishing neurosurgical team in Korea

March 1951–March 1952

	Name	Source of Culture	Organism	Sensitivity					Recovery
				Pen	Strep	Chloro	Aureo	Terr	
1.	E.J.	Subgaleal	Hemolytic staphylococcus	0	+	+	+	+	+
			Nonhemolytic staphylococcus	+	+	+	+	+	
			Escherichia coli	0	0	+	0	+	
			Clostridium perfringens	0	0	0	0	0	
			Aerobacter aerogenes	0	0	+	0	+	
		Pus from brain	Sterile						
		Spinal fluid	Sterile						
2.	L.H.	Spinal fluid	Hemolytic staphylococcus	0	0	0	+	+	+
		Subdural granuloma	Hemolytic staphylococcus	+	0	0	+	+	
3.	D.M.	Spinal fluid	Hemolytic staphylococcus	0	0	+	0	+	+
			Hemolytic staphylococcus	+	0	+	+	+	
		Flap tap	Nonhemolytic staphylococcus	0	0	+	0	+	
4.	N.N.	Spinal fluid	Pseudomonas aeruginosa	0	+	+	0	0	+
5.	A.S.	Flap tap	Hemolytic staphylococcus	0	0	0	0	0	0
			Paracolon bacillus	0	0	0	0	0	
		Spinal fluid	Hemolytic staphylococcus	+	0	0	0	0	
			Aerobacter aerogenes	0	sl.	sl.	sl.	0	
			Gamma streptococcus	?	?	?	?	?	
			Paracolon bacillus	0	0	0	0	0	
			Nonhemolytic staphylococcus	0	0	0	0	0	
6.	W.R.	Spinal fluid	Hemolytic staphylococcus	0	0	0	0	0	+
			Escherichia coli	0	+	0	0	0	
			Pseudomonas aeruginosa	0	0	sl.	0	0	
			Alcaligenes faecalis	0	0	+	0	0	
		Brain fungus	Alcaligenes faecalis	0	0	+	0	0	
			Hemolytic staphylococcus	+	0	+	+	0	
			Escherichia coli	0	+	0	0	0	
7.	Q.H.	Right ventricle	Alcaligenes faecalis	0	0	+	+	+	+
8.	A.M.	Flap tap	Hemolytic staphylococcus	+	0	+	0	0	+
			Bacillus subtilis	0	+	+	+	+	
		Spinal fluid	Sterile						
9.	W.W.	Brain and ventricle	Hemolytic staphylococcus	+	0	+	0	0	0
		Spinal fluid	Hemolytic staphylococcus	+	0	+	0	0	
10.	V.S.	Extradural	Hemolytic staphylococcus	0	0	+	0	0	+
			Gamma hemolytic staphylococcus	+	0	+	+	+	
		Brain	Alpha streptococcus	+	0	0	+	0	
			Hemolytic staphylococcus	0	0	+	0	0	
		Spinal fluid	Aerobacter aerogenes	0	0	0	0	0	
11.	J.T.	Extradural	Proteus species	0	0	+	+	0	0
			Hemolytic staphylococcus	0	0	+	+	0	
			Flavobacterium	0	0	+	+	+	
			Alpha streptococcus	0	0	+	0	0	
		Spinal fluid	Proteus species	0	0	+	0	0	
		Brain abscess	Proteus species	0	0	0	0	0	
			Hemolytic staphylococcus	0	0	0	0	0	

Pen = Penicillin
Strep = Streptomycin
Chloro = Chloromycetin
Aureo = Aureomycin
Terr = Terramycin
sl. = slight

eign bodies. The subdural space was inspected in all cases as occasionally a subdural clot was encountered. Ventricular clots and foreign bodies were removed under direct vision when present. All wounds were copiously irrigated. Following complete debridement of all space-occupying clots, devitalized cerebral tissue, and foreign bodies, the missile canal remained well retracted. This, no doubt, was also aided by the opening into the ventricular system with free drainage of ventricular fluid. However, if active cerebritis was present with associated edema, there was less tendency for the walls of the missile tract to remain widely separated.

All wounds were closed tightly following debridement unless active cerebritis was present. In the latter cases, instead of the exteriorization method,[2,13] the wounds were left wide open and the cerebral tissue was repeatedly irrigated with sterile saline solution.[15] Cerebral herniation was controlled with repeated spinal taps.[18] Appropriate antibiotics were given systemically. No intrathecal or intraventricular medications were used. After the cerebritis had subsided, usually in 4 to 6 days, intracranial toilet was accomplished in the operating room and dural closure was achieved with fascial graft or other means (Table 5).

The choroid plexus was found to be torn in 12 cases of this series and it was cauterized or removed in 10. In the other cases it had thrombosed and extruded spontaneously.

Gelfoam was used in the missile tract in 18 of our early cases to seal off the opening into the ventricle. In several re-operative cases the gelfoam was encountered floating about freely in the porencephalic cyst that communicated with the lateral ventricle. The possibility of a loose fragment of gelfoam blocking the foramen of Monro or the cerebral aqueduct was thought in retrospect to have been the cause of some of the transitory bouts of increased intracranial pressure in some of the postoperative cases. The possibility of gelfoam acting as an avascular focus for infection was also considered and its use as a seal in the ventricular opening was discontinued. Its value as a hemostatic agent during surgery has been well established and for this purpose it was utilized freely in our series.

Dural closure is of great importance in the surgical treatment of trans-

TABLE 5

Dural Closure

Pericranial graft	8
Temporal fascia graft	12
Fascia lata graft	67
Occipital fascia	1
Dural closure (primary)	2
Muscle stamp	1
Gel film closure	12
Dura not closed (split-thickness graft applied to brain)	2
Total	105

ventricular wounds. Fascia lata graft was used in 67 cases, temporal fascia in 12, pericranium in 8, and occipital fascia in 1 (Table 5). Primary dural closure was used in 1 case, and muscle stamp for associated dural-blood sinus tear in 1 case. In 2 cases the dura mater was not repaired. In these 2, a direct skin graft was applied on the granulating cerebral tissue, much by the same technique as has been described by Webster.[24] Early in our series, gel film or fibrin film for dural closure was attempted in 12 cases of transventricular wounds. One sealed without difficulty, 3 sealed following repeated scalp flap and spinal taps, and 8 required re-operation because of cerebral herniation or persistent fistulous formation. In 5 of these cases the dura mater was closed with a fascial graft; in the remaining 3 it was reclosed with gel film and subsequently sealed after repeated scalp flap and spinal taps.

Primary closure of the scalp is also of great importance, particularly when dural grafting has been done. We saw several cases in which necrosis of the dural graft, fistulous formation, and cerebritis developed because of inadequate scalp closure. Rather than accomplish closure under tension, rotation of a scalp flap with a wide base from an area of intact bone was used. The skin flap was rotated to cover the entire operative craniectomy defect and a split-thickness graft was applied to the intact periosteum at the site from which the rotation flap was raised. We found it advisable to apply the split-thickness graft immediately rather than as a delayed procedure.

Postoperative. Meticulous observation by the ward surgeon is of utmost importance. The usual methods of positioning the comatose patient, resuscitation, suctioning, changing position, catheterization, etc., were employed.

In cases of infection appropriate antibiotics were administered systemically. A great deal of importance was placed on culture and sensitivity reports that could be obtained within a 24-hour period. Penicillin was not used in conjunction with aureomycin, chloromycetin, and terramycin, because of their alleged antagonistic actions. Intravenous fluids were given to the comatose patients for a period of 24–48 hours postoperatively. Then nasogastric tube feedings were employed. When this stage was reached, all antibiotics were administered by this method. Table 4, sections A and B, shows the organisms involved in the infections in this series, as well as the culture and sensitivity reports when available. It may be noted that Neill and Segerberg[17] reported only 1 known case of recovery from *Aerobacter aerogenes* in World War II. In this series, 2 patients with meningitis caused by *Aerobacter aerogenes* and 5 with *Pseudomonas aeruginosa* (pyocyaneous) infection recovered. Antibiotics were administered for 10 days to patients without obvious infection, and for at least 3 weeks to those with infection. In the latter, this included a period of at least 10 days after there was no gross evidence of infection as determined by spinal taps with cell count and culture studies.

All head dressings were changed approximately 4–6 hours after surgery, utilizing sterile technique and individual sterile dressing sets. The dressings were then changed one to two times a day until complete healing had re-

sulted. At the time of each changing, the scalp over the craniectomy site was inspected and palpated. Subgaleal fluid collection was treated by aspiration under sterile technique.

Spinal taps were frequently employed in the management of postoperative transventricular wounds. The actual palpation of the skin flap over the craniectomy defect was the deciding factor. Individual cases varied in regard to frequency of taps and the amount of the fluid removed. We saw no untoward results from taps as frequent as every 8 hours with removal of 60–100 cc. of fluid, provided that tap of the flap was done prior to spinal tap when there was extradural fluid. A tendency of overproduction of spinal fluid was noted for several days following surgery in practically all cases of transventricular wounds. By careful observation of the scalp flap, graded, serial spinal punctures were employed in such a fashion that the time interval between the taps was lengthened and the amount of the fluid removed was reduced. Dural graft leaks were sealed on several occasions by combined flap and spinal taps. In cases of infection, cell counts, culture and sensitivity test were done at least once a day until all evidence of infection subsided.

Superficial scalp sutures were removed within 48 hours in most cases, thus depending on the buried galeal sutures for closure. The patients were maintained on bedrest for a period of 4 days following surgery. Then they were started on sitting up, ambulation and physiotherapy.

Hemoglobin and hematocrit values were maintained at a level above 14 gm. and 40 gm. per cent respectively.

Postoperative skull films were taken on the 4th day. Retained bone fragments were indicative of further operative procedures.

Evacuation to the United States was made upon completion of all definitive therapy except cranioplasty, physiotherapy, and rehabilitation.

FACTORS IN MORTALITY

A review of the autopsy reports in the 11 fatal cases in this series shows that the cause of death was primarily infection in 9, intraventricular hemorrhage in 1, and severe generalized diffuse brain damage in 1.

SUMMARY

A report based on 105 consecutive cases of transventricular wounds of the brain verified at surgery is presented. The over-all mortality rate was 10.47 per cent. The importance of early definitive surgery was stressed. The value of a reliable, quick method of obtaining culture and sensitivity test was pointed out. The availability of some of the newer antibiotics administered systemically was an important factor in overcoming some of the seemingly hopeless infections. The pre-operative, operative, and postoperative management was outlined.

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TUMORS OF THE FORAMEN MAGNUM OF SPINAL ORIGIN

EDMUND A. SMOLIK, M.D.,* AND ERNEST SACHS, M.D.†
St. Louis, Missouri

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TUMORS in the region of the foramen magnum may be divided into two groups: (1) those arising primarily in the posterior fossa and extending downward into the foramen magnum and (2) those arising primarily in the upper cervical cord and extending upward into the foramen magnum. The former are essentially brain tumors and the symptoms and signs in this group are primarily those of brain tumors; the latter are more strictly spinal tumors and these are spoken of as spinocranial and cause the symptoms of a spinal tumor.

The occurrence of such spinal tumors is relatively rare. In the series of 234 verified spinal cord tumors from the Sachs collection, there were 6 verified cases or an incidence of 2.5 per cent. It seemed worth while to call attention to their occurrence and as far as possible to correlate some of the common characteristics of their symptomatology.

Other case reports and collected series indicate their relatively rare occurrence but this may suggest a higher unrecognized incidence. Elsberg and Strauss,[6] in a report of 185 cases of spinal cord tumors, found 3.7 per cent in the foramen magnum. Love and Adson[10] reported 23 cases, 12 of which were definitely craniospinal. Elsberg,[5] Abrahamson[1] and Symonds and Meadows,[16] attempted to describe the findings in foramen magnum compression. Strully, *et al.*[15] called attention to the protean and insidious neurologic manifestations of high cervical lesions caused by compressions other than neoplasms. Piehl, Reese and Steelman[12] called attention to the spinocranial syndrome as described by Bogorodinski. Until recently, the diagnosis has been infrequently made ante mortem and still less often has surgical treatment been performed. That the actual incidence of these lesions may, however, be greater than heretofore suspected, is suggested in a report by Bennett and Fortes.[2]

Study of the cases recorded in the literature,[4,7,11,13,17] as well as the cases reported here, indicates that the capricious and bizarre picture frequently diagnosed as demyelinating disease or infectious disease of the central nervous system may, in fact, be caused by a tumor at the foramen magnum.

* Associate Professor of Neurological Surgery, St. Louis University School of Medicine, St. Louis, Missouri.

† Research Associate, Departments of Surgery and History of Medicine, Yale University School of Medicine, New Haven, Connecticut. Formerly Professor of Clinical Neurological Surgery, Washington University School of Medicine, St. Louis, Missouri.

The true diagnosis can be arrived at only by careful correlation of symptoms, signs, spinal fluid dynamics, chemistry and use of contrast myelography.

The following 6 cases of spinocranial tumors describe the train of symptoms and signs encountered in our series. In 5 instances the diagnosis was made and operative procedure was carried out, and in 1 case the diagnosis was not established until post mortem. These cases also illustrate the gravity of surgical interference when the disease is far advanced.

CASE REPORTS

Case 1. #9507. H.V.D., a 46-year-old white female, was admitted to Barnes Hospital on Feb. 12, 1942. Her illness had begun in the Fall of 1941 when her neck became stiff and ached a good deal, at times so severely as to make turning of the head impossible. This persisted in spite of osteopathic treatments.

Seven weeks before admission, numbness and tingling developed in the fingers of both hands, more marked on the left. These sensations spread progressively up her arms, involving her chest. She stated that her lungs felt tight and heavy. The sensation of heaviness spread through the abdomen and finally to her lower extremities. As the numb, dead feeling became more severe, the patient lost the use of her extremities except for a slight movement in the right hand and right leg. Throughout this period, the symptoms were more marked in the early morning, improving during the day. She was hospitalized at another institution, where, 4 nights before entry into Barnes Hospital, another woman, who was mentally deranged, attempted to choke her. From that time on the patient was unable to speak above a whisper. No change was noted in function of her bowels or bladder until 8 days before entry, when constipation became extreme. On the night before entry, she had incontinence of urine. There had been a gain of 25 lbs. in weight in the last 6 months.

Examination. Temperature was 37.5°C., respiratory rate 24 per min., pulse rate 110, and B.P. 120/75. The patient was a well developed, obese woman, apparently not suffering from any pain and quite adjusted to her environment. She was alert, cheerful, cooperative and showed no signs of apprehension.

There was no involvement of the cranial nerves. There was slight tenderness at the base of the skull on passive movement of the neck but no rigidity. At the 2nd or 3rd cervical dermatomes there was a disturbance in the temperature sense forming a collar type of deficit, but this was not constant. Deep reflexes were hyperactive and equal but superficial reflexes were absent. There were bilateral Babinski and Hoffmann signs. The tone of the rectal sphincter was poor.

Laboratory Data. Blood and urine were normal. Kahn was negative. Lumbar puncture and Queckenstedt test were performed on Feb. 13, 1942. The initial pressure was 190 mm. of water. When the left jugular was compressed there was good response but not on compressing the right. Lumbar puncture on Feb. 16, 1942, showed a rise when both jugulars were compressed. The fluid was turbid and pinkish in color. The cell count, with acid, was 9; without acid 234, nearly all fresh red cells. Pandy was 4 plus; Wassermann negative; colloidal gold curve 0001111223; and total protein 1,173 mg. per cent. A second lumbar puncture performed on the same day showed 3,700 red cells without acid, 17 cells with acid; total protein was 1,043 mg. per cent. A provisional diagnosis of Guillain-Barré neuronitis was made.

Course. On Feb. 17, 1942, her temperature suddenly rose to 41.0°C. Her pulse rate was 130, and respiratory rate 30. Respirations gradually increased in depth, with apneic pauses of 30 to 40 sec. occurring every 5 to 10 min. Pulmonary edema de-

veloped and the heart sounds were distant. Two and one-half hours following this sudden elevation of temperature, the patient vomited 200 cc. of brownish-red material. In spite of oxygen therapy and supportive treatment, she died.

Autopsy. The leptomeninges over the spinal cord and the cerebrospinal fluid were rust-red in color. Situated at the foramen magnum and extending downward toward the 1st cervical vertebra and in the left posterior quadrant was a grayish-white tumor measuring $1\frac{1}{2} \times 2$ cm. (Fig. 1). The tumor was attached to the dura mater and pressed on the spinal cord in a forward direction. Diagnosis: Intradural tumor of the upper cervical segment and foramen magnum with compression of the spinal cord.

Microscopic Diagnosis. Arachnoidal fibroblastoma (meningioma).

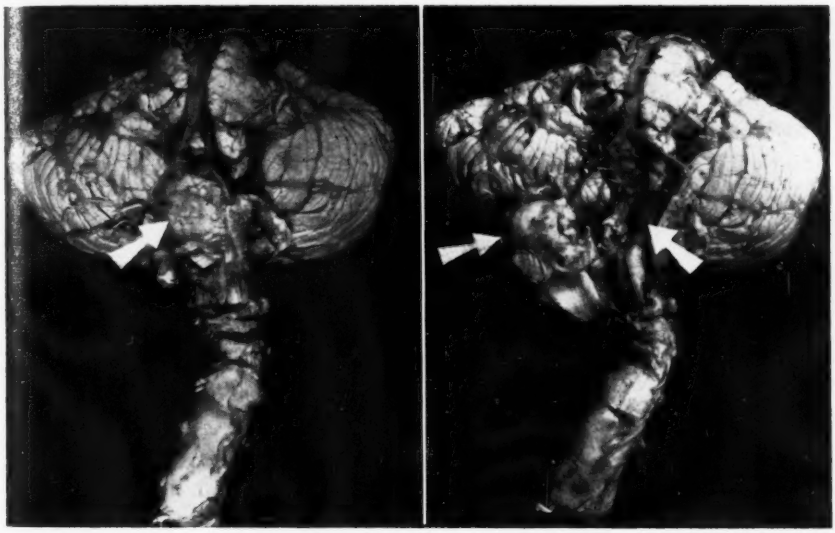


FIG. 1. (*Left*) Tumor compressing the cisterna magna. (*Right*) Tumor swung laterally to expose distorted upper cervical cord and medulla.

Case 2. #102641. P.I.Z., a 52-year-old white female, entered Barnes Hospital with a history that about 1 year before entry she had begun to suffer intense occipital headaches. At that time she was going through menopausal changes and was thought to have a menopausal psychosis. Treatment of 10,000 units of Theelin every 2 or 3 weeks was prescribed. This she took at irregular intervals without improvement. The headache was so intense that she was given codeine and aspirin. She had marked personality change during this period, becoming morose and sullen.

In the 8 months prior to admission she had complained of slight weakness of the right arm. This became progressively worse during the last month, and on admission she was unable to move her right arm and leg. She also suffered from severe constipation which necessitated daily enemas. Two months before admission she had begun to take morphine for relief of her occipital pain.

Following admission, the patient had a syncopal attack during which her blood pressure dropped to 80/60. She complained that she could not get her breath. The possibility that this was a withdrawal symptom was considered. An EEG done at

this time showed myocardial damage of coronary type. A myocardial infarction, however, could not be definitely demonstrated. She also had infection of the bladder. On digitalis therapy she improved gradually but was considered a poor surgical risk.

Neurological Examination. The patient was an emaciated, white woman lying uncomfortably in bed with her head tilted to the left. She was only moderately cooperative. There was no nystagmus. The corneal reflexes were intact and no sensory disturbances of either 5th nerve were noted. There was a suggestion of a slight right facial weakness. There was weakness of the right sternocleidomastoid and trapezius muscles. There was marked weakness of the right arm with almost total paralysis. There were no tremors and no astereognosis. Biceps, triceps and radial reflexes were present and equal bilaterally. There was a right Hoffmann sign. Kinesthetic sensation could not be tested because the patient was uncooperative. Abdominals were absent bilaterally. There was complete loss of function of the right leg with a foot drop, but knee jerks and ankle jerks were approximately equal. There was no demonstrable clonus but there was a suggestive right Oppenheim and Babinski reflex.

Laboratory Data. Red count was 4.36, hb. 12.7 gm., and white count 6,000 with normal differential. The urine showed a 1 plus albumin and many white cells. Kahn was negative. N.P.N. was 18 mg. per cent and fasting blood sugar 74 mg. per cent. CSF was slightly xanthochromic with an initial pressure of 130. Queckenstedt test showed a complete block; there were 40 cells with acid and total protein was 480 mg. per cent with a 4 plus Pandy.

A diagnosis of cervical cord tumor in the region of the foramen magnum was made.

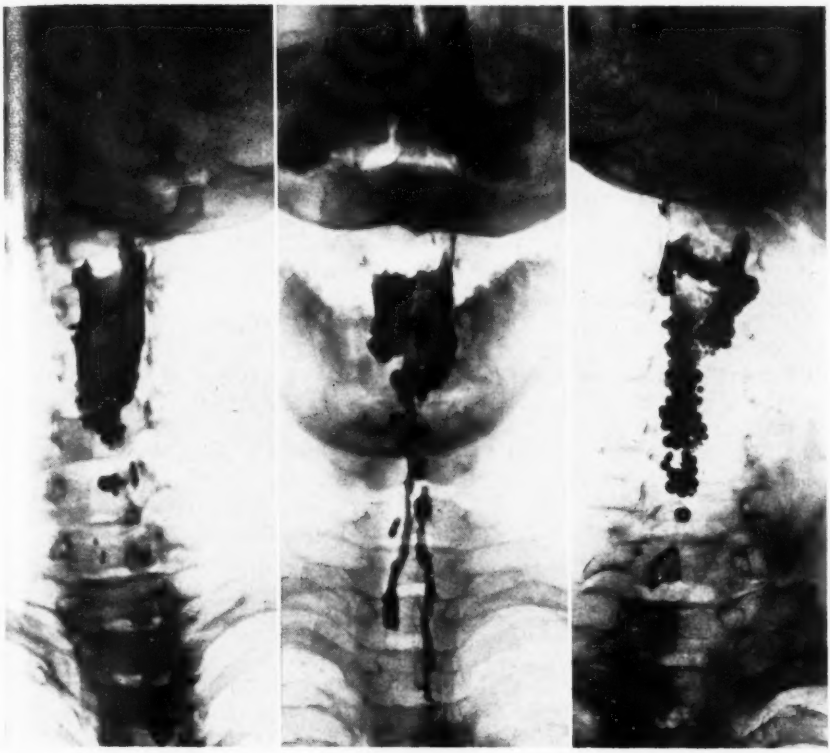
Operation. On Jan. 18, 1943 lipiodol was injected into the lumbar space which showed a complete block at C2 (Fig. 2). Under endotracheal anesthesia, a laminectomy was done with removal of the 1st, 2nd and 3rd cervical spinous processes, the foramen magnum, and the lower portion of the occipital bone. The dura mater was opened in the region of C2 and the incision was carried upward, exposing a tumor which was lying on the right side of the cord. Huge vessels covered the tumor and ran over the cord. The left edge of the tumor was tightly adherent to the medulla and was dissected away with some difficulty. As it was lifted up, the patient experienced some difficulty in breathing. The tumor extended up into the lower portion of the 4th ventricle; it was lifted up and removed without any hemorrhage. Closure was then made in the usual manner.

Course. Immediately after the operation the patient responded well but, on the 2nd postoperative day, she began to have some difficulty in breathing. There was a chest lag on the right side. In spite of oxygen and chemotherapy for a bilateral bronchopneumonia, death occurred on the 11th postoperative day.

Autopsy revealed that the tumor had been completely removed but there was myelomalacia of the right lateral columns of the cord.

Pathological Diagnosis. Arachnoidal fibroblastoma (meningioma). Tumor weight: 7 grams.

Case 3. #88942. V.E.S., a 36-year-old white female, entered Barnes Hospital on April 22, 1941. She had been in good health until 8 years previously, when, during the 4th month of her gestation, she began to notice weakness of the right hand and difficulty in handling objects. This progressed until at the time of delivery she had a complete right hemiparesis. This gradually improved during the following 15 months so that she was able to do her housework for about 10 months. From this time on, she began to see various doctors because of the weakness of her right side



FIGS. 2, 3 and 4. Myelograms demonstrating block at C1 and C2 level in Cases 2, 3 and 5 respectively

and various paresthesias. No diagnosis was made. She was given a course of sex hormone therapy for 2 months.

Between 1936 and 1939, she had periods of dull cramping pain in her right thigh. In 1938 the paresis in the right upper extremity reappeared and spread to the right lower extremity. At times it was associated with dull, cramping pains in the muscles of these extremities. In 1939 she was in another hospital, where a diagnosis of multiple sclerosis was made. She was given intensive Vitamin B therapy. There was no improvement and, from 1940 on, the progressive loss of power in the right side increased until she again became completely hemiplegic. At the same time there were periods when she complained of paresthesias in the left foot, leg, hand and arm. Some weakness of the left hand also developed. During the 8 years of her illness she had had attacks of urinary incontinence and dysuria but these were followed by periods in which she had normal control. At times she had had gross muscular twitchings in the right extremity but no fibrillary movements were noted.

Neurological Examination. She was a fairly well developed, well nourished, white woman lying quietly in bed. Temperature was 37.5°, pulse rate 38, respiratory rate 16, and B.P. 120/75. She was alert, oriented and apparently was in no pain. The left

pupil was larger than the right but both reacted to light and in accommodation. There was slight lateral nystagmus to the right and left. The fundi were normal. The right shoulder could not be shrugged and there was definite weakness of the right sternocleidomastoid and trapezius muscles. There was a spastic paralysis of the right arm and leg. Power of the left arm and leg was diminished. All tendon jerks were hyperactive and equal. Abdominal reflexes were absent. There were bilateral Hoffmann, Babinski, Oppenheim and Chaddock reflexes and a bilateral ankle clonus. Diminution of sensation was noted from the 2nd cervical dermatome down. There was some impairment of stereognostic ability in the right hand. Vibratory sense was diminished over the legs and absent below the knees.

On lumbar puncture, the initial pressure was 150, with a normal rise and fall on jugular compression; there was no evidence of a block.

Laboratory Data. The spinal fluid contained 5 cells; Pandy was negative and total protein was 133 mg. per cent. Blood and spinal fluid Wassermann tests were negative. Colloidal gold curve was 0013311000. Spinal fluid removed on May 5, 1941 before the injection of lipiodol showed a total protein of 254 mg. per cent. Myelography was carried out, which showed a complete block at the level of C2 (Fig. 3).

RBC was 4.78, hb. 70 per cent and WBC 8,650, with normal differential. Blood count was normal. Urine was normal and stool was negative for guaiac.

Operation. On May 8, 1941, under avertin, an incision was made from the occipital bone down to the 4th cervical spinous process. The muscles were dissected away from the occipital bone and from the 1st, 2nd and 3rd cervical vertebrae. The spinous processes of C2 and C3 were removed and the exposed dura mater did not pulsate. The posterior part of the atlas was then removed and, when the dura mater was opened, a tumor extending along the right side of the cord was disclosed. In order to get an adequate exposure, the posterior portion of the foramen magnum and lower portion of the occipital bone were removed so that both cerebellar lobes were exposed. The dural incision was then carried upward. The cisterna magna was obliterated by the tumor. It had displaced the medulla to the left and was lying in front of the ligamentum denticulatum. It was removed in toto. Closure was made in layers, with silk.

Course. The patient made an uneventful postoperative recovery. Her paralysis cleared up almost completely and she now does all her work.

Pathological Diagnosis. Arachnoidal fibroblastoma (meningioma). Tumor weight: 14 grams.

Case 4. #103657. B.S., a 56-year-old white male, entered Barnes Hospital in February 1943 with the complaint of stiffness of his neck for 3 years. He had had impotence for 1 year, numbness of the left hand for 1 year and weakness of his right hand and both legs for 2 or 3 months. He had experienced a sensation of tightness about his chest for 2 or 3 weeks. He had been seen at another clinic 7 months before admission at which time no definite diagnosis had been made.

Examination. The following findings were noted: no impairment of any cranial nerves, stiffness of the neck, spasticity of the arms, more marked on the right, and diminution of strength in grips on both sides. There was some questionable hypesthesia to pin prick over the left forearm. All tendon reflexes were hyperactive, with bilateral ankle and patellar clonus. There was a positive Hoffmann on the left. No pathological toe signs were found. Position sense was normal. Abdominal reflexes were absent. The patient was up and about but had a spastic gait with legs feeling

stiff and weak. There was some difficulty in beginning urination and some decrease in the caliber of the stream.

Laboratory Data. Lumbar puncture was done which showed no block. There were 3 cells; total protein was 79 mg. per cent; colloidal gold curve 0013331100; Wassermann negative; Pandy negative. X-rays of skull and cervical spine were non-contributory except for some arthritic spurring in the spine.

Course. The patient was discharged as a possible tumor suspect; spastic paraplegia, cause unknown.

2nd Admission. He was re-admitted 4 months later with definite progression of his symptoms. There were increasing stiffness and weakness of both legs. Stiffness of the neck was still present. In addition he complained of numbness over the left arm and the left side of the body and inability to tell the difference between hot and cold on the left side. He did not complain, at this time, of numbness of his right arm and hand but there was weakness of the right hand which had progressed to almost complete paralysis of the right arm with only slight flexor movements of the fingers. The weakness of the legs had steadily increased.

Two months before admission the patient had had a urinary infection and two episodes of pain on passing his urine, associated with chills and fever. He had had his bladder irrigated at another hospital. The patient was constipated.

Two weeks prior to this 2nd admission, there was pain in the right arm. He had never experienced pain in the legs or left side of the body. Occasionally he had pain in the neck.

Examination. The patient was well developed and obese, in no acute distress but lying motionless in bed, able to move only his left arm. His speech appeared normal and his memory was good. There was weakness of both trapezius muscles. There was complete paralysis of the right arm. The left grip was weak but all movements were preserved. Biceps and triceps reflexes were greatly exaggerated on both sides. Hoffmann sign was absent. There was spastic paraplegia of the lower extremities with a few flexor movements of the toes. Tendon reflexes were hyperactive and there was a bilateral ankle clonus. Abdominal reflexes were absent. There was absent sensation to pain and temperature from C1 down on the left side of the body.

A diagnosis of high cervical cord tumor was made.

On July 2, 1943 lipiodol was injected, which showed separation of the lipiodol column at the 5th cervical vertebra. There was no complete block.

Operation. Under avertin, a laminectomy was performed. The upper cervical cord was exposed. The dura mater did not pulsate. The occipital bone was then opened over the cerebellum and the posterior part of the foramen magnum was removed. The dura mater was split upward. The spinal cord at the level of the 1st cervical segment and the medulla bulged markedly, as if pushed back by a tumor, but no tumor was disclosed. More bone was removed laterally on the right side and the cord was retracted gently, and then a tumor was found lying anterior to the spinal cord in the midline in the basilar groove. Even this slight manipulation of the cord affected the patient's respiration. More bone was taken away and the capsule of the tumor was split. It was obviously a meningioma. A curette was inserted into the tumor but the tumor itself could not be mobilized. The capsule and tumor were then removed piecemeal. These manipulations interfered with the patient's respiration and he died of respiratory failure before the operative procedure could be completed.

Pathological Report. There was a $2\frac{1}{2} \times 2 \times 2$ cm. oval-shaped mass of tumor compressing the medulla oblongata and lying between the two vertebral arteries. The tumor had compressed the spinal cord, thinning it to a ribbon-like structure measuring at its greatest thickness only 7 mm. The tumor was well circumscribed, and there were a few small nodules on its surface which could be shelled out from the dura mater and the brain tissue surrounding it. The dura mater over the tumor was markedly thickened but in no area did it appear to be actually invaded by the tumor.

Pathological Diagnosis. Arachnoidal fibroblastoma (meningioma) involving the anterior surface of the medulla oblongata and the 1st and 2nd cervical sections of the cord.

Case 5. #113390. R.H.T., a 49-year-old white male, entered Barnes Hospital on April 18, 1944. He had been perfectly well until 1 year previously, when he first noticed a sensation of stiffness in his neck, which was not accompanied by pain. The stiffness did not disturb him greatly. Shortly after its onset he began to notice a sensation of numbness and tingling, and a feeling of "pins and needles" in the right upper and lower extremities. These sensations became more marked, but were never felt on the left side. About 4 or 5 months prior to admission, weakness occurred in the right hand and arm and in the right lower extremity, which gradually progressed so that for 2 weeks prior to entry the patient had been unable to move the right upper extremity at all and had been able to walk only by dragging the right leg. He had noticed no weakness of the left extremities. Four or 5 months previously, he had had occasional episodes in which he seemed to be short of breath and unable to speak except in a very low voice or whisper. These spells came on at irregular intervals and usually lasted only a few minutes. They did not seem to be related to any particular activity. He had had urinary incontinence only since admission to the hospital. There was no history of trauma.

Examination. He was a well developed, well nourished male who appeared comfortable and not acutely ill. He was cooperative. There was no fixed attitude of the head. There was no noticeable impairment of speech. The sternomastoid and trapezius were weak on both sides, more on the right than on the left. The fundi were normal and there was no nystagmus. The patient was unable to perform any movements with the right upper extremity, which appeared somewhat swollen. There was slight weakness of the left arm. On both sides sensation to touch and pin prick was diminished from the 2nd cervical dermatome down. The tendon jerks were all hypoactive, more on the right than on the left. There was bilateral astereognosis. Hoffmann sign was positive bilaterally. Abdominal and cremasteric reflexes were absent. There was complete loss of motor power of the right lower extremity and some loss of power on the left. There was bilateral inexhaustible ankle clonus. All pathological toe signs were positive. There was slight nuchal rigidity but no tenderness nor deformity.

Laboratory Data. On lumbar puncture a partial block was found: 31 cells; 4 plus Pandy; total protein 273 mg. per cent; colloidal gold 3444333210, and Wassermann negative. Lipiodol injection showed a block at the foramen magnum (Fig. 4).

Operation. On April 4, 1944 a laminectomy was done. Incision was made over the occipital bone and over the 1st, 2nd and 3rd cervical vertebrae. The dura mater did not pulsate and the occipital bone was rongeured away over the posterior part of the cerebellum and the cisterna was exposed. After opening the dura mater at the level of the 2nd cervical vertebra, a nodular tumor was exposed on the left side of

the cord. The inferior cerebellar artery had to be carefully dissected away from the tumor, which lay to the left and anterior to the spinal cord and projected into the 4th ventricle. The tumor was removed completely. Closure was made with silk in layers.

Course. The patient had a completely uneventful postoperative course and when examined recently, was walking with only a suggestion of slightly spastic gait on the right. He was up and back at work.

Pathological Diagnosis. Arachnoidal fibroblastoma (meningioma). Tumor weight: 7 grams.

Case 6. #421225. I.B., a 33-year-old white female, entered Jewish Hospital in February 1942. She had been well until the birth of her first child in 1937, 5 years previously. Her weight before pregnancy was 136 lbs.; at term she weighed 160 lbs. Her weight subsequently increased and, at time of admission, was 196 lbs. She felt weak at all times. Following the birth of her second child, 2½ years before admission, her periods had returned and recurred at irregular intervals for a year but she had had no flow for the last 12 months.

Eighteen months before admission the patient began to feel tightness in her neck, "like a stiff neck." She could not turn her neck easily. Tonsillectomy was advised and performed. This did not relieve her stiff neck. She next noticed numbness in the right thumb which spread to the right hand and right forehead, shoulders and chest. Then the left hand was similarly affected. She noticed weakness first of the right arm, then of the left and increasing difficulty in walking for 1 year before admission. For the last 6 months she had had headache and, 1 month prior to entry, the arms had become so weak that the patient had difficulty in feeding herself.

Examination. The patient was an obese, white female who appeared in no acute distress. B.P. varied from 180/100 to 160/100. Her face was typical of Cushing's syndrome. Her cheeks were reddened and blown. The hair was prominent over the upper lip and chin and well developed on the forearms and legs. There was a tendency toward male pubic hair distribution. Her neck was very short. Her abdomen was domeshaped. There were purplish striae over the abdominal wall and thighs. There was diminished sensation from the 1st cervical dermatome down. There was an almost complete spastic quadriplegia. All deep reflexes were hyperactive. Abdominal reflexes were absent. Bilateral Hoffmann and Babinski signs and ankle clonus were elicited. There was no cranial nerve involvement.

Laboratory Data. Urine was normal. Kahn was negative. Routine blood was negative. There was a low sugar tolerance.

Comment. The patient presented the classic signs of Cushing's syndrome including obesity, plethora, amenorrhea, nuchal fat pads, red abdominal striae, decreased sugar tolerance, hirsutism and hypertension. In addition there were the signs of spinal cord compression at a high level. Queckenstedt test revealed a complete block. The fluid was xanthochromic and the total protein was elevated. Lipiodol was injected through the lumbar meninges and myelography showed a block at C1.

A diagnosis of Cushing's syndrome and spinal cord tumor at the level of foramen magnum was made.

Operation, Feb. 2, 1942. There was a very thick fat pad over the neck and the occipital area so that a very long incision had to be made. The spinous processes of the 1st, 2nd, 3rd and 4th cervical were removed. On exposing the dura mater, no extradural fat was found and the dura mater did not pulsate. The muscles were peeled off the occipital bone, much of which was then removed, exposing the

posterior fossa and the upper cervical cord. When the dura mater was opened, a tumor lying posterior to the spinal cord was exposed. The tumor extended up into the 4th ventricle. It was nodular and obviously a meningioma. The tumor was attached to the dura mater over the foramen magnum. With its dural attachment it was removed en masse from the foramen magnum and the 4th ventricle. After removal, a depression was left in the region of the 4th ventricle and the 1st cervical segments. The dura mater was then closed over the spinal cord but the cerebellar dura mater was left open. Closure was made in layers.

Course. The patient had an uneventful postoperative course except for a superficial breakdown of the wound. She was up and walking at time of discharge.

She was re-admitted to Barnes Hospital on Dec. 8, 1943 for chemical studies. During the postoperative interval her weight had dropped to 163 lbs.

DISCUSSION

The neurological data of a series of 6 spinocranial tumors are summarized in Table 1. During the early stage of tumor formation these patients presented changing and vacillating symptoms and signs. It is at this stage that a variety of diagnoses are made. Abrahamson and Grossman[1] suggested that the early neurological manifestations are caused by distortion of the cord. Only when compression of the cord begins do the signs become definite and identifiable.

TABLE 1

Summary of neurological data

Case No.	Duration of Symptoms	Stiff Neck or Headache	Bladder Deficit	Sexual Disturbances	Choked Discs	Motor Deficit	Sensory Deficit	Cranial Nerve Defect	Nystagmus	Pupil Change	"Astereognosis"
1	14 mos.	+	+	0	0	+	+	0	0	0	?
2	1 yr.	+	0	+	0	+	0	VII XI	0	−	−
3	8 yrs.	0	+	0	0	+	+	0	+	+	+
4	3 yrs.	+	0	0	0	+	+	XI	0	−	−
5	1 yr.	+	+	0	0	+	+	XI	+	−	+
6	1½ yrs.	+	+	+	0	+	+	0	0	−	−

Characteristically most of the patients, sooner or later, complain of pain or stiffness in the neck or headache. Unilateral sensory and/or motor changes occur. These are usually homolateral. Late symptoms are frequently of bladder and, at times, sexual disturbances. Rarely are the cranial nerves involved, and, in this series, choking of the discs was not encountered.

Weinstein and Wechsler[18] and Rubinstein[14] have reported the finding of astereognosis in patients with lesions of the posterior fossa involving the upper portion of the cervical cord. One of Rubinstein's cases was from the Neurosurgical Service at Barnes Hosital. It is not included here, as it belonged to the craniospinal group. We do not believe the term astereognosis should be applied to cases in which there is a gross sensory disturbance. In true astereognosis there should be no other demonstrable sensory disturb-

ance. When marked sensory disturbance is present, such dissociation had better be spoken of as stereo-anesthesia.[3]

The presence of Cushing's syndrome in Case 6 may have been a coincidental occurrence, but it is of great interest that with removal of the tumor those symptoms disappeared in the course of a year. Descending pathways from the hypothalamus have been traced to the pontine level and almost certainly these exist at lower levels. That Cushing's syndrome is related to lesions of the hypothalamic nuclei has been suggested by Heinbecker.[8] Whether removal of the direct pressure on the medullary tracts played a role in the regression of symptoms or whether relief of a slight degree of internal hydrocephalus, as suggested by Heinbecker,[9] was responsible, is a matter of speculation in Case 6. We had no positive evidence of hydrocephalus. Also of interest is the increase of 25 lbs. in weight during the development of symptoms in Case 1.

Cerebrospinal fluid findings are summarized in Table 2. In all instances the total protein content of the spinal fluid was elevated. In 2 cases, complete block, and in 1 case, partial block to Queckenstedt was present. In all 4 cases there was a block or deformity in the myelogram.

TABLE 2

Summary of cerebrospinal fluid findings

Case No.	Initial CSF Pressure	Pandy	Cells	Xantho-chromia	Total Protein Mg. %	Colloidal Gold	Queckenstedt Block	Myelogram
1	190	4+	9	?	1173	0001111223	Partial	Not done
2	130	4+	40	+	480	0001100000	Complete	Block
3	150	0	5	0	133 (254) 5 days.	0013310000	0	Block
4	170	0	3	0	79	0013331100	0	Block 2nd Entry
5	130	4+	32	0	273	3444333210	Partial	Block
6	240	4+	4	+	261	0001123222	Complete	Block

SUMMARY

1. A series of 6 tumors of the foramen magnum (spinocranial) is presented.

2. These cases illustrate the insidious onset of spinocranial tumors and the great variability of the early symptoms.

3. Patients with suboccipital headache who manifest pyramidal deficits and capricious sensory symptoms may well have a tumor of the foramen magnum.

4. It is important to resort to high cervical myelography if the total protein is elevated.

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THROMBOSIS OF SUPERIOR SAGITTAL SINUS

CAUSED BY TRAUMA WITHOUT PENETRATING INJURY

A. W. CARRIE, M.D., AND FREDERICK A. JAFFÉ, M.D.

Department of Neurosurgery, Hospital for Sick Children, Toronto, and Department of Pathology, Toronto Western Hospital, Toronto, Ontario, Canada

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TRAUMA is an uncommon cause of intracranial venous sinus thrombosis, especially in the absence of penetrating injury. Two patients died recently at the Hospital for Sick Children as the result of head injuries suffered in automobile accidents. At autopsy both patients revealed recent thrombosis of the superior sagittal sinus without fracture of the skull. As we were able to find only 1 similar case in the literature and as some of our observations on subsequent cases of head injury appear to elucidate the pathogenesis of this condition, it was felt that a report of these 2 cases was justified.

CASE REPORTS

Case 1. A 10-year-old boy was hit by a motor car travelling at approximately 30 miles per hour. On admission to hospital he was unconscious and cyanotic. A large amount of blood was removed from the trachea by suction and an endotracheal tube was inserted. There were two abrasions and a haematoma over the left frontal region and abrasions over the left maxilla. No blood was seen behind the ear drums. The pupils were equal and reacted to light, and the corneal reflexes were present. Initially the reflexes were normal and the plantar responses were downgoing. There was an obvious fracture of the right femur, which was immobilized in a Thomas splint. The patient manifested mild shock on admission which responded quickly to the administration of plasma. The blood pressure then remained normal until immediately prior to death.

His neurological state deteriorated quite rapidly and 5 hours after admission he showed a bilateral extensor Babinski response, slight dilatation of the left pupil, increased muscular tone in the extremities and decreased movements of the right arm and leg. The right side of the chest did not move well and this was not improved by bronchoscopic suction. A lumbar puncture revealed blood-tinged fluid without xanthochromasia under a pressure of 450 mm. of water. About 36 hours after admission fixed pupils developed and the patient died as preparations were being made to do burr holes.

Autopsy. The body was that of a well developed male child showing the superficial abrasions of the skin that had been noted on clinical examination. The right leg was externally rotated. The findings included a transverse fracture of the shaft of the right femur, a linear fracture of the left iliac bone and a small tear in the lower pole of the left kidney which had resulted in moderate haemorrhage into the retroperitoneal and peripelvic tissues. Multiple subpleural and parenchymal haemorrhages were seen throughout both lungs.

Patchy haemorrhagic extravasations involved the deep surface of the scalp over the left frontal, parietal and occipital regions. The skull was intact throughout. A firm, friable thrombus occluded the lumen of the superior sagittal sinus in its entire length but not including the confluence of the sinuses. The lacunae as well as the other dural sinuses were patent and grossly free of thrombus. The superficial cerebral veins appeared congested and there were diffuse patches of subarachnoid haemorrhage over both cerebral hemispheres, particularly on the left side.

The brain weighed 1590 gm. The cerebral convolutions were slightly flattened but there was pronounced swelling of the brain stem and pons. No other lesions were noted on gross inspection. The spinal cord was not examined.

Microscopical examination of the brain stem and pons confirmed the presence of edema with considerable vascular congestion, widening of perivascular spaces and early degenerative changes in neurons. No haemorrhages were encountered. Sections of the cerebral hemispheres also showed vascular congestion but this was less conspicuous than in the brain stem and pons.

The lumen of the superior sagittal sinus was completely occluded by a laminated thrombus of recent origin (Fig. 4). Its wall showed extensive haemorrhage which had reached the lumen in several areas. The endothelial cells in these areas were swollen and appeared to be desquamating.

Case 2. A 4-year-old boy ran into the rear fender of a moving car and was thrown to the ground. When first seen by a physician he was not deeply comatose but resented being handled. He gradually became more restless and vomited frequently. He moved his right extremities more than the left.

On admission to the Hospital for Sick Children on the following day he was unconscious, flailing the left arm and leg aimlessly with spasticity of the right leg and flaccidity of the right arm. There was very severe swelling of the left temporal region and a convergent left squint, the left eye being turned downwards. The pupils were small and reacted to light. The corneal responses were absent. The right plantar response was upgoing, the left equivocal.

Skull x-rays showed no evidence of fracture. Lumbar puncture revealed slightly yellow fluid under a pressure of 145 mm. of water. A fixed right pupil developed, with elevated temperature and Cheyne-Stokes breathing.

Bilateral burr holes were done 5 days after admission but no evidence of extradural or subdural blood clot was found. The patient died 7 days after admission in respiratory failure.

Autopsy. The body was that of a well developed male child showing superficial abrasions of the skin above the right eye and bridge of the nose. One recent surgical incision was present in each temporoparietal region.

Internal examination of the thorax and abdomen revealed no significant findings apart from marked congestion and early consolidation of the lower lobes of both lungs and the presence of large amounts of tenaceous mucus in the trachea and bronchi.

Apart from the operative wounds the skull was intact. There was diffuse subdural and subarachnoid haemorrhage, particularly over the right cerebral hemisphere. The brain weighed 1530 gm. There was flattening of gyri, most marked over the left temporal, right parietal and occipital lobes. Multiple small areas of cortical contusion were seen over the right occipital lobe. On section, after fixation, marked swelling of the brain stem and pons was noted. The superior sagittal sinus was completely occluded by loosely adherent thrombus throughout its extent.

Microscopic examination of the sinus showed an appearance similar to that encountered in Case 1. The lumen was occluded by recent thrombus and patchy haemorrhages could be seen in the sinus wall. Sections of the brain stem and pons were also similar to those in Case 1 but the cerebrum showed a greater degree of vascular congestion, edema and damage to neurons.

PATHOGENESIS OF TRAUMATIC SINUS THROMBOSIS

The extensive thrombosis of the superior sagittal sinus which was found in the 2 cases reported above appeared to have been the result of severe blows to the head and to have largely contributed to death. It was, therefore, felt to be of interest to explore the pathogenesis of this lesion and to study the effects of trauma upon the superior sagittal sinus in general.

Thrombosis within any vessel is generally regarded as being caused by one or more of three factors: abnormalities of the clotting mechanism of the blood, disturbances of blood flow, and injury to the lining endothelium. The first of these can be excluded with reasonable certainty because haematological abnormalities were neither suggested by the clinical history of these two children nor indicated by the autopsy findings. The second factor, disturbances of blood flow, is more difficult to evaluate. Case 1 manifested a brief period of mild shock and had suffered considerable loss of blood into the lungs, the retroperitoneal space, the scalp and the regions of the leg and pelvic fractures. No such period of shock was detected in Case 2 and the blood loss was minimal.

The walls of the superior sagittal sinus contain small sinusoids which represent the continuations of the contributory veins. These sinusoids are devoid of any muscle coat and consist merely of an endothelial lining sup-

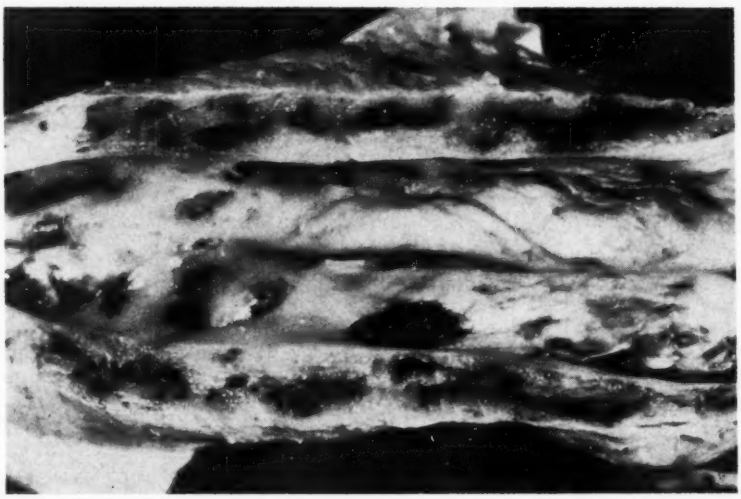

FIG. 1. Longitudinal section of the superior wall of the superior sagittal sinus. There are multiple scattered intramural haemorrhages.

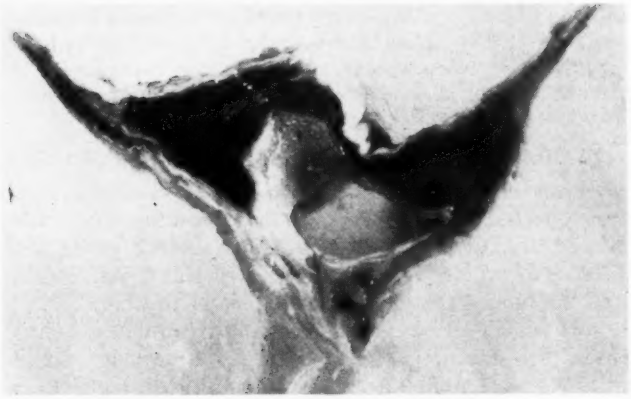

FIG. 2. Cross section of the superior sagittal sinus showing massive intramural haemorrhage into its superior wall.

ported by the connective-tissue stroma containing a few elastic fibrils. The lining of the sinus itself has a similar architecture (Fig. 5). One of the striking features of the superior sagittal sinus in the 2 cases reported was the presence of multiple small haemorrhages within its wall. These were most numerous in its superior wall although not confined to that area (Fig. 4). These intramural haemorrhages were caused by rupture or complete disintegration of these delicate sinusoids. The small arteries, also present within the wall of the sinus but endowed with a muscular media, were intact (Fig. 3).

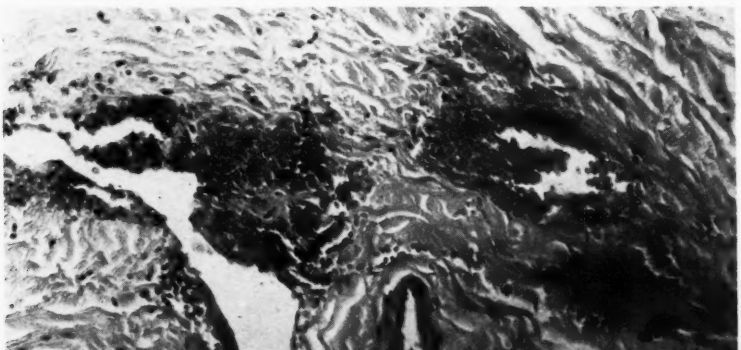

FIG. 3. Photomicrograph of the wall of the superior sagittal sinus showing rupture and disintegration of intramural sinusoids. The small arteries remain intact. (×200)

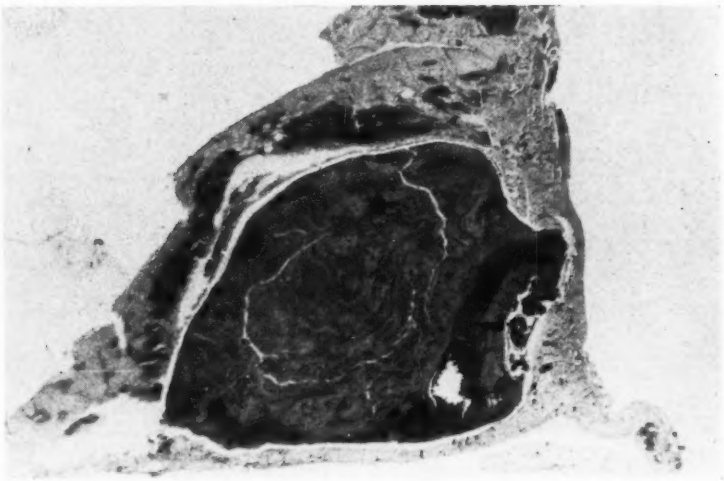

FIG. 4. Photomicrograph of the superior sagittal sinus of Case 1, showing occlusion of the lumen by thrombus and intramural haemorrhage. (×10)

In many areas these haemorrhages had encroached upon the lumen of the sinus and led to injury of the lining endothelium (Fig. 5).

Since the presence of intramural haemorrhage and the resulting injury to the lining cells might afford an explanation of the subsequent occurrence of thrombosis, the superior sagittal sinus of 11 other patients with head injury was examined at autopsy. In 3 of these cases gross evidence of intramural haemorrhage was found.

One case was that of a 63-year-old man who had received a blow to the left side of the head during a fight. He had suffered a depressed fracture of the skull in the left temporoparietal region and lacerations of the brain in that area. He died 2 hours after admission to hospital. The superior sagittal sinus showed multiple small haemorrhages throughout its entire extent, particularly in its superior wall (Fig. 1). The second case, that of a 51-year-old man who had fallen onto a concrete floor from a standing position, suffering a basal fracture of the skull and dying almost instantaneously, revealed the most massive intramural haemorrhage that we have so far encountered. It extended throughout the length of the superior sagittal sinus and encroached upon, but did not appear to occlude the lumen of the sinus (Fig. 2). The third case was that of a 15-year-old boy who died of abdominal injuries 10 hours after an automobile accident. He had apparently struck his head against the pavement, as shown by superficial abrasions of the face and scalp, but had not suffered a skull fracture or grossly evident injuries to the brain. The superior sagittal sinus also showed many small haemorrhages in its wall.

All of these cases showed microscopically rupture of intramural sinusoids

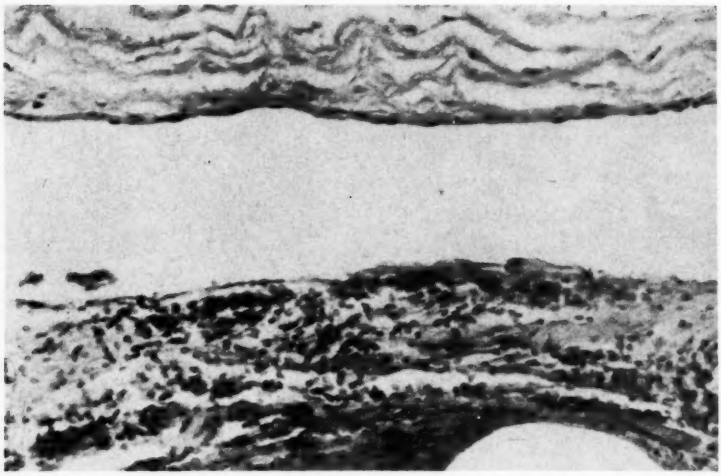

FIG. 5. Section of the wall of the superior sagittal sinus showing its normal structure in the upper portion of the photograph and haemorrhage involving the endothelial lining in the lower portion. (×300)

but none of them revealed thrombosis. Extensive injury to the lining endothelium was found in the case of the massive haemorrhage.

It thus appears that haemorrhage into the wall of the superior sagittal sinus is a relatively frequent result of trauma to the head. The delicate structure of the sinusoids, in contrast to that of the small arteries, might well explain their great susceptibility to trauma. The relatively fixed position of the superior wall of the sinus probably accounts for the greater frequency of the haemorrhages in that area. Whether endothelial injury is the only factor in the production of thrombosis or whether other factors, particularly slowing of the blood stream, also play an essential role remains to be determined. There seems little doubt, however, that endothelial injury would greatly predispose the sinus to the deposition of platelets upon its wall and to subsequent thrombosis.

The marked degree of edema of the brain stem and pons that was encountered in the 2 cases of sinus thrombosis suggests that the blood vessels of these areas participate in the establishment of a collateral circulation, possibly via the straight sinus and the lateral sinuses. Apart from the investigations of Browder and Kaplan,[4] little is known regarding the possible channels of collateral venous drainage following occlusion of the superior sagittal sinus.

Further studies are now in progress concerning the routes of collateral circulation and the effects of trauma upon the other venous sinuses.

REVIEW OF THE LITERATURE

There are numerous reports of injuries to the venous sinuses of the dura mater by missiles. As early as 1895 Hershey[8] described the case of an 8-year-

old girl who had been struck on the vertex in such a way that a triangular fragment of bone lacerated the superior sagittal sinus. Wharton[15] in 1901 reported 70 patients with wounds of the sagittal and lateral sinuses, 5 of whom had been under his care. Most of these had an overlying depressed fracture of the skull. Attempted repair often resulted in fatal haemorrhage.

The clinical picture produced by sudden occlusion of the superior sagittal sinus was described in 1915 by Holmes and Sargent[10] in a study of 70 cases seen in World War I. Initial flaccidity of the limbs was soon followed by spasticity, particularly of the shoulder and elbow of the upper limb and the ankle and knee of the lower limb. The hand, fingers and hip were seldom involved. Both the arms and legs were internally rotated. In 20 of their cases all limbs were affected, in 31 both legs and one arm and in 16 only the lower limbs. A sensory ataxia, with impairment of gross sensory perception, and some loss of position and movement sense were observed. In some cases the function of the bladder was also disturbed. The general symptoms of increased intracranial pressure were present in all cases. Holmes and Sargent did not operate upon the majority of these patients because of the danger of severe haemorrhage. They found that gradual improvement usually occurred because, presumably, of the development of a collateral circulation. As most of their patients recovered and as they did not report any autopsy findings in the remainder, it is neither possible to state to what extent the sinus was occluded nor whether thrombus was responsible for the occlusion.

Cushing[6] made reference to this work in his study of craniocerebral wounds in the first World War. However, he was of the opinion that the superior sagittal sinus syndrome could occur without thrombosis of the sinus, merely as the result of contusion of the vertex.

Cairns and his co-workers[5] found a high incidence of thrombosis of the venous sinuses at autopsy in cases of head wounds in World War II. In 28 cases of penetrating brain wounds they found 11 in which there was antemortem venous sinus thrombosis. In 8 of these the thrombosis was in one of the major venous sinuses and in 6 it was at a considerable distance from the site of the injury. In all of these cases the thrombus was firm and not infected.

Thrombosis of the superior sagittal sinus as the result of trauma without penetrating injury or fracture of the skull was first reported by Bagley[1] in 1934 and we have been unable to find any other report of similar cases in the English literature. The 2 cases here reported would seem to be similar to his case of a 9-year-old victim of an automobile accident. This boy was unconscious and thrashing about on admission to hospital. He had generalised convulsive seizures starting with extreme rigidity of the limbs. Lumbar puncture revealed bloody fluid under a slightly increased pressure. The patient died on the 10th day after admission. Autopsy revealed dilatation of the veins emptying into the superior sagittal sinus and a thrombus which filled the lumen of the sinus from the torcular backwards for two thirds of its length. Early organisation of the thrombus was present. There had been no fracture of the skull.

Clinical, pathological and experimental studies support the contention that extensive intracranial venous sinus thrombosis can cause death. Neurosurgeons have had considerable experience with the results of resection of portions of the superior sagittal sinus in dealing with parasagittal meningiomas. Jaeger,[12] on the basis of 10 cases of his own and 15 others reported in the literature, concluded that the superior sagittal sinus could be ligated or resected safely anterior to the point at which the rolandic veins enter the sinus irrespective of whether or not a tumour was compressing or occluding this structure. It also appeared safe to remove a portion of the sinus at or posterior to the rolandic veins, provided the sinus had already been slowly occluded by a tumour. Death invariably followed resection of an unoccluded superior sagittal sinus at the entrance of the rolandic veins. It might be concluded that obstruction of the sinus by thrombus at this site would have the same effect.

Isolated reports have appeared in the literature of superior sagittal sinus thrombosis without obvious cause which resulted in death. Hirsch[9] reported 1 such case and found haemorrhagic necrosis of the cerebral cortex, presumably caused by this thrombosis. Bailey and Hass[2] also found intracerebral haemorrhages or softenings in cases of superior sagittal sinus thrombosis following meningitis. Intracranial venous sinus thrombosis sometimes complicates the puerperium, and Hyland[11] cites Stanfield, who found that the mortality rate was 56 per cent when this complication was recognized. These observations indicate the serious effects of sinus thrombosis.

Experimentation has been carried out on animals having a cerebral venous drainage different from that of man so that these results cannot be applied directly to human cases.[3] The most interesting approach to the problem has been that of Browder and Kaplan.[4] In 44 experiments carried out on fresh human autopsy specimens, they were unable to fill the superior cerebral veins by injecting a contrast medium under a pressure of 100 mm. of mercury into the superior sagittal sinus, the sinus being ligated just rostral to the torcular. With a pressure of 600 mm. of mercury partial filling of the cortical veins was obtained in 8 cases. They concluded that there was a valve-like action at the junction of the cerebral veins and the superior sagittal sinus which prevented reflux from the sinus. Injections of various media into the cerebral veins immediately lateral to the sinus demonstrated a relatively free anastomosis between all the cortical cerebral veins. Browder and Kaplan were able to demonstrate anastomoses in the anterior frontal region, at the sphenoparietal sinus, between the rolandic and sylvian groups of veins and between the rolandic and posterior groups of veins. They felt that it was unlikely that these connections were sufficiently large to accommodate the volume of blood that would be shunted through them by the sudden occlusion of more than one of the four major groups of cerebral veins that join the superior sagittal sinus. These workers, therefore, felt that these channels could not constitute an effective collateral circulation.

DIAGNOSIS AND THERAPY

The rarity of sinus thrombosis makes its diagnosis difficult. Some increased tone in the limbs seems to be a fairly constant feature. This condition should be suspected in all patients with head injury who present evidence of increasing cerebral dysfunction but have no clinical or operative signs of extradural or subdural clot. Ray and his associates[13,14] have suggested the use of superior sagittal sinus venography for the diagnosis of the condition in non-traumatic cases. They injected 35 per cent diodrast into the sinus through a burr hole. They reported one case in which a thrombus was demonstrated by this method. The patient received anticoagulants after its surgical removal and improved gradually. The same technique might be applied to cases of head injury in which sinus thrombosis is suspected.

The evaluation of therapeutic procedures such as surgical removal of the thrombus, must await cases in which an antemortem diagnosis had been established. On theoretical grounds anticoagulant therapy would appear to be indicated in order to prevent extension of the thrombotic process. However, the presence of other injuries or intracranial haemorrhage would undoubtedly be a frequent contraindication to the administration of anticoagulants.

SUMMARY

Thrombosis of the superior sagittal sinus can occur as the result of trauma without penetrating injury or fracture of the skull. Two cases in which the diagnosis was established at autopsy are reported. Studies of other cases of fatal head injury indicated that intramural haemorrhage caused by rupture of small sinusoids was a common sequel of trauma to the head and that the resulting injury to the lining endothelium might predispose the sinus to thrombosis.

The literature regarding thrombosis of the superior sagittal sinus was briefly reviewed.

The authors are greatly indebted to Dr. William Keith, Neurosurgeon to the Hospital for Sick Children, for permission to publish the two cases of sinus thrombosis and to Dr. Chester R. McLean, Pathologist to the Toronto Western Hospital, for granting them access to the pathological material of the second case.

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CONGENITAL LUMBOSACRAL MYELOMENINGOCELE WITH INCONTINENCE

A CONTRIBUTION TO THE UNDERSTANDING OF BLADDER PHYSIOLOGY*

EBEN ALEXANDER, JR., M.D., FRED K. GARVEY, M.D., AND WILLIAM BOYCE, M.D.

Sections of Neurosurgery and Urology, Department of Surgery, Bowman Gray School of Medicine, Winston-Salem, North Carolina

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ADVANCES in the care of paraparetic and paraplegic patients during the last 20 years are well known. The mortality of patients with paraplegia has been sharply reduced and the life expectancy of the individual patient has been lengthened by the prevention of decubiti and the elaboration of practical methods for long-term rehabilitation of such persons. Of even greater importance is a better understanding of bladder physiology with a reduction in the incidence of chronic urinary tract infection, one of the more common causes of death in paraplegic patients in years past.

The value of the contributions by such pioneers as Head and Riddoch,[12] Munro,[20,21] and others cannot be overestimated. More recently the papers of Prather,[23] Lewis,[15] Freeman and Heimburger,[10,11] Botterell and coworkers,[1] Shelden and Bors,[24] and numerous others have made possible a better understanding of the physiological functions of the normal human bladder and of the human bladder deprived of connections with the brain, or on occasions, with the spinal cord.

In brief, it has been found that in a patient with a spinal cord severance above the conus medullaris there may develop, after weeks or months, a bladder with the power to empty completely and automatically, a hypotonicity of the bladder with large residual, or a severe hypertonicity with small capacity. The weight of evidence points to the S3 anterior nerve roots as the principal nerve supply, reflex or otherwise, to the detrusor action of the bladder. The anterior S2 and S4 roots carry some fibers to the bladder but are of much less importance than the anterior roots of S3.[22] Consequently, in performing anterior rhizotomy for the relief of reflex motor spasms of the legs in paralyzed patients, warning has been given to spare the S3 anterior roots.[16] This warning in general has seemed to be of importance, since after bilateral anterior rhizotomy of D10 through S1, patients with severe reflex spasms of the legs with poor bladder function have usually developed improved bladder automaticity.

On the other hand, Shelden and Bors,[24] and more recently Stellar,[25] have

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demonstrated similar improvement in bladder function in paraplegic individuals in whom they have injected 15 cc. of absolute alcohol into the lumbar subarachnoid space. Similar studies by Meirowsky, Scheibert, and Hinchey[17,18] in severing the S3 and S4 anterior roots have shown improvement in bladder function in certain patients. The injection of absolute alcohol undoubtedly destroys the S3 anterior roots, previously felt to be so important in the reflex emptying of the bladder. Heimburger and Freeman[13] have improved the capacity and emptying of the bladder of certain paraplegic patients with hypertonic bladders by procaine injection of the S3 roots bilaterally.

Patients born with varying degrees of congenital anomalies known as meningocele or myelomeningocele in the lumbosacral or lower thoracic region often present problems similar to those seen in patients rendered paraplegic by trauma, tumor or infection. There are often other congenital anomalies of the nervous system or of other parts of the body, and these, combined with the disturbed function associated with the paraplegia in early life, contribute to a high mortality in this group. The number of such patients who survive to the age of 20 is not accurately known, but is probably small.[4] Judging from the report of Fisher, Uihlein, and Keith[9] of 350 cases seen at the Mayo Clinic, this would be about one in ten. However, the series included patients with cranium bifidum in whom the mortality is lower, and their report did not give details as to the number of patients with such congenital defects of the lower spine who survived to the age of 20 years. Likewise, the reports of Ingraham *et al.*[14] and of Cohn and Hamby[5] do not clarify that point.

There is little question, however, that the incidence of incontinence of urine and feces in patients with meningocele and myelomeningocele of the lumbosacral region is high.[5] Numerous surgeons have attempted to alleviate these difficulties with control of excreta by colostomy, ureterosigmoid anastomosis, the creation of closed loops of bowel in which the urine can be stored, and numerous mechanical aids for the control of urethral emptying of the bladder. It is only fair to say that no one of these methods has succeeded in benefiting such patients with sufficient frequency to be adopted as a standard procedure. It is possible, however, that the application of knowledge gained about the reflex emptying of the bladder in paraplegic patients can be used to advantage in certain patients with congenital lesions of the lower spine. The apparent success to date of a procedure in which this was done has stimulated this report.

CASE REPORT

NCBH No. 136996. M.D., a 23-year-old single white female, was admitted on Jan. 16, 1952 for correction of urinary incontinence.

When she was born it was noted that she had a small dimple in the midline over the sacrum. She had been incontinent of urine and feces since birth. There had been weakness of the legs and deformities of the feet, the latter requiring arthrodesis. Her mental development had been normal and her physical development, except for the abnormalities already noted, was normal. There had been no difficulties

above the level of the waist, the head was not enlarged, and the neck was not stiff. She had succeeded in maintaining fairly satisfactory bowel control by remaining constipated and giving herself an enema every day or every other day.

Her urinary control, however, was a serious problem. She was wet almost constantly. In September 1951 she was admitted to another hospital where after extensive studies with cystometrograms the external urethral sphincter was tightened by an anterior colporrhaphy. This had resulted in her remaining dry for as long as 2 hours during the day but necessitated firm suprapupic pressure for emptying of the bladder. She still was not continent of urine at night.

There was no history of deformities in other members of her family.

Examination. Temperature was 98°, pulse rate 80, respiratory rate 16, and B.P. 120/80. The patient was well proportioned and attractive. There were no abnormalities above the level of the chest.

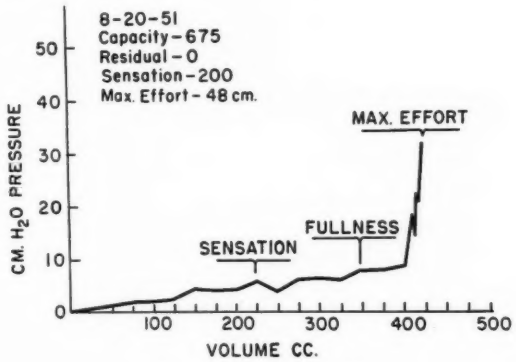

FIG. 1. Preoperative cystometrogram.

She walked slowly with a limp on the left side. There was a midline dimple of the skin over S2-S3, measuring 1 to 1.5 cm. in diameter and covered by thin translucent skin. When the skin was retracted downward, there was a deep indentation of the dimple, indicating an attachment cephalad to this point.

There was poor development of the legs. There was marked weakness of plantar flexion and moderate weakness of dorsiflexion of the feet, much greater on the left. The scars of operation for arthrodesis of the ankle were evident on the left side.

There was almost complete anesthesia below L4 on the left and below S1 on the right. There was complete saddle anesthesia and in only isolated spots could the patient distinguish gross painful stimuli on either leg below L5. There was relaxation of the anal sphincter.

Blood was normal. NPN was 32 mg. per cent. Urine contained 1–2 WBC per high power field; concentration was 1.014; albumin was negative.

Roentgenograms of the lumbar spine showed a widening at the spinal canal at L4 and L5, with a spina bifida at L5.

Intravenous pyelography disclosed no abnormality of the upper urinary tract. A cystometrogram showed a hypotonic type of bladder with gradual rise until the bladder reached 400 cc., at which time there was a fairly sharp rise in the column of fluid (Fig. 1). There was residual urine of between 90 and 110 cc.

Electromyograms of the bladder were made by previously described technique.[2,3,6,7] An especially constructed sheath* was passed through the urethra and two ball electrodes of silver-silver chloride were brought into contact with the bladder wall near the base. The insulated spring leads maintained one electrode in contact with either lateral bladder wall during the examination. A third channel of the sheath, connected to an irrigation flask and water manometer, permitted variation in the degree of distention of the viscus and observations of change in intravesical pressure. The electrodes were connected to the Grass electroencephalograph Model III-C and the bioelectric action potentials accompanying muscular activity of the detrusor were recorded in wave form. Spontaneous and voluntary muscular activity of the bladder was thus studied in the resting or nearly empty bladder and with varying degrees of filling. The electromotive force (E.M.F.) and duration of

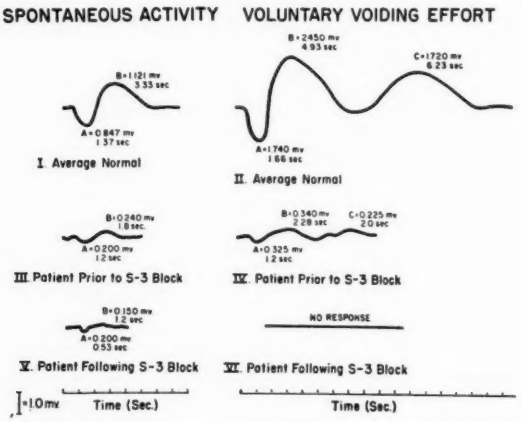

FIG. 2. Electromyographic records of muscular activity of the bladder.

each electropotential shift or wave was calculated as previously described.[6,7] The interpretation of these records, as based on previous experiments, would indicate that the initial A wave is unaccompanied by muscular contraction and is thought to represent spread of the excitatory process, while the ensuing B and C waves of a single electropotential shift are accompanied by muscular contraction. The magnitude of the E.M.F. of the B or C wave at any given instant is a function of the vector sum of the bioelectric action potentials of all the excited muscle cells at that particular moment and hence an indication of the mass of active muscle. The duration of a single B or C wave is considered to be a reflection of the integration of detrusor activity as successive contractions of contiguous muscle cells occur. For example, spasm of a large part of the detrusor is represented in the electromyogram by a very high E.M.F. of up to 8.0 mv. but of relatively short duration.

The results of this examination of the patient on two occasions prior to operation were identical. Fig. 2 illustrates the average spontaneous waves obtained from the resting bladder. These were of shorter duration and the average E.M.F. was less than that of the normal bladder (Fig. 2). Unlike the normal, which exhibits a spon-

* Provided by Mr. Frederick J. Wallace of the American Cystoscope Makers, Inc., New York, N.Y.

taneous pattern of strikingly constant duration and E.M.F., there was a marked variation in the E.M.F. of both A and B waves, and an occasional wave was much greater than normal with a maximum of 1.52 mv. for the A and 1.90 mv. for the B waves. In no instance was there a duration of either A or B waves that approached the normal. Voluntary efforts to void resulted in electromyograms of considerably less than normal E.M.F. and duration.

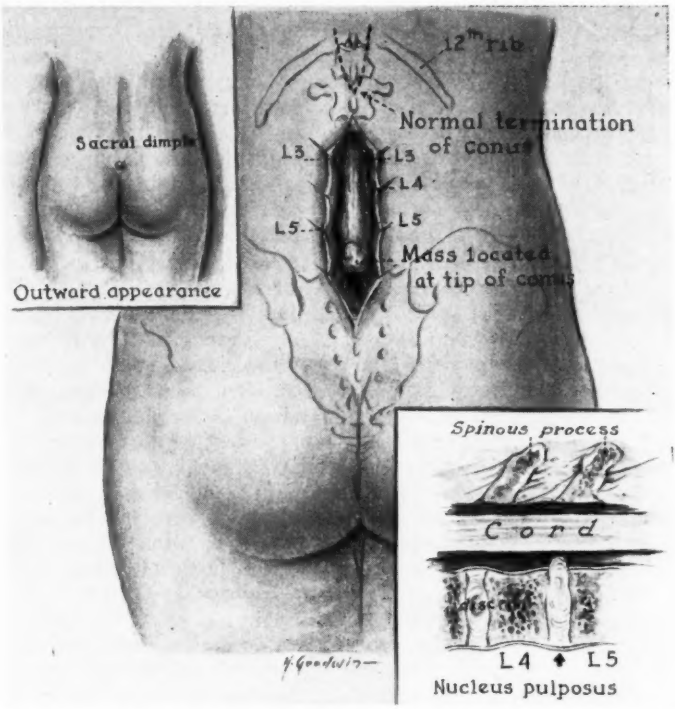

FIG. 3. Artist's drawing of operative findings. The herniation of the nucleus pulposus at L4 was considered an incidental finding.

It was concluded that these studies indicated abnormal parasympathetic innervation of the bladder with poor integration of the detrusor as a whole and occasional "spasmodic" contractions. Muscular contractions appeared to be limited to segments of the bladder that, in the absence of either normal bladder tonus or a satisfactory mass contraction of the detrusor as a whole, were incapable of emptying the viscus.

Pantopaque myelography on Jan. 21, 1952 showed an unusually wide sacral canal over the lower lumbar region with a very sharp midline defect at L4. The column of oil deviated around this on either side without obstruction. It was of interest that the patient experienced a considerable amount of pain during the insertion of the needle, but the spinal fluid was clear, free of cells and contained protein of 30 mg. per cent.

1st Operation, Jan. 23, 1952. The fibrous tract leading directly to a globular mass of firm tissue attached to the dorsal tip of the conus medullaris was excised (Fig. 3). This was a direct fibrous communication between the skin and the spinal cord. Laminectomy at L4 and L5 was carried out, the laminae of the latter being soft and cartilaginous. The ligamentum flavum beneath L5 was intact and removal of it permitted dorsal expansion of the dura mater as if it had been constricted by this tissue. When the dura mater was opened, it was apparent that the tip of the conus medullaris lay at the level of L5-S1. The canal was at least twice as large in all diameters as normal at this level. Associated with this caudal location of the conus medullaris, the L3 nerve roots passed upward at an angle of 10 to 20° in their course from the spinal cord to the intervertebral foramina. The L4 root on the right passed transversely outward, that on the left was absent. The L5 root on the left was larger than the other roots, and both L5 roots, right and left, passed downward slightly to their exit from the spinal cord to the intervertebral foramina. The sacral roots were small and were asymmetrically placed, the intervertebral foramina on the left being 2 to 3 mm. lower than those on the right.

There was a 2.0 cm. mass of scar tissue on the dorsal tip of the conus to which the fibrous tract in the skin was attached. Except for meticulous division of all fibrous connections between this and the surrounding dura mater, it was not otherwise disturbed or dissected. It resembled grossly the mass of nerve tissue often seen at the base of a myelomeningocele removed from the lumbosacral region of infants.

At the level of L4 in the midline there was evident, when the cord was displaced to the right, a very prominent bulge anterior to the cord. Because of the wide diameter of the canal and the attachments of the cord to the nerve roots, the cord was suspended dorsally and it was found that this mass was apparently not in contact with the cord. It was white, 1 cm. high, and 0.6 cm. broad at its base. The anterior dura mater was opened and the mass, which was cartilaginous, was removed. The pituitary rongeur could be passed into the intervertebral space through the opening created by removal of the protrusion, and further fragments of the intervertebral disc were thus removed. It was the impression at the time of operation that this mass, prominent as it was by myelography and at the time of direct visualization, did not actually contribute in any way to the patient's disability. It was completely removed. Following this, the dura mater was tightly closed and the wound was closed with silk. The patient withstood the operation well.

Pathological Diagnosis. Fibrocartilage.

2nd Operation. After satisfactory healing of the wound had taken place, the patient was returned to the operating room on Jan. 30, 1952 and under general anesthesia the wound was re-opened. A #18 Foley catheter was inserted into the bladder and attached to a water cystometer apparatus. The nerve roots were again identified, using as identification the 4th lumbar interspace at which the protrusion of cartilage had been removed and the 2nd sacral interspace at which a silver clip had been placed at the 1st operation and confirmed by a roentgenogram taken before the 2nd operation.

The level of the cystometer was adjusted to that of the partially filled bladder.

Stimulation with 8 volts of faradic current resulted in movement of the hips and legs when the L3 and L4 roots were stimulated. Stimulation of the 5th lumbar and 1st and 2nd sacral roots resulted in no muscular movement and no change in the level of the cystometer.

Stimulation of the 3rd sacral root on the left resulted in a rise of fluid level in the

cystometer of 11 cm. On the right side the rise was approximately 5 cm. These results were obtained on repeated stimulations of equal voltage.

Stimulation of the S4 roots and of the filum terminale gave no response.

The 3rd sacral roots were then carefully isolated bilaterally and crushed with a straight hemostat. Anterior and posterior roots were not separated because of their small size. All remaining roots were left intact. The wound was closed in layers with silk.

Postoperative Course. An indwelling catheter was left in place. On one occasion when the catheter was removed, a residual of 1200 cc. developed and the patient was not able to empty her bladder at that time. She was discharged from the hospital with the catheter in place.

Feb. 13, 1952. The patient was able to void 200 cc. of urine with a residual of 60 cc. Her urine contained a few pus cells.

Feb. 18, 1952. The patient voided 300 cc. with complete emptying of the bladder.

Feb. 28, 1952. The bladder held 400 cc. of urine; no infection, and no residual. She found that she could hold her urine 8 hours without voiding and was not wet at night.

Aug. 7, 1952. Patient maintained her bladder control 4 to 5 hours at a time without emptying her bladder. She then emptied her bladder completely without residual. She had had no pain. She was not incontinent at night.

Sept. 26, 1952. The cystometrogram was repeated (Fig. 4). The bladder showed the typical hypotonic chart. There was no infection of the urinary tract. Electromyograms of the bladder at this time indicated only an occasional wave occurring about once in 3 minutes in the resting bladder with very low E.M.F. and of short duration (Fig. 2). There was complete absence of any bioelectric potential with voluntary efforts to void.

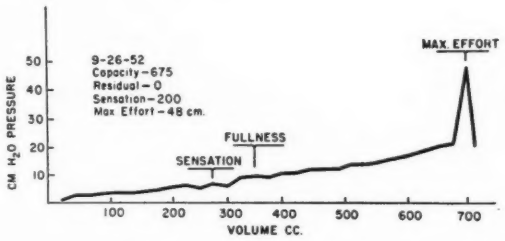

FIG. 4. Postoperative cystometrogram.

DISCUSSION

The exact mechanism by which the function of this patient's bladder has been so strikingly improved by crushing of the 3rd sacral roots is not at once evident. Correlation of the cystometric and electromyographic studies suggests that she had marked hypotonia of the detrusor with contractile hyperactivity of segmental character.[3] These hyperactive segmental contractions were completely abolished by block of the 3rd sacral roots. It is conceivable that elimination of these segmental "spasms" may permit an integrated contraction of the detrusor as a whole. The "trigger" mechanism for such an emptying contraction may arise from the intrinsic innervation

of the detrusor, either as a result of physiologic filling of the bladder ("stretch reflex"), or a sudden increase in intravesical pressure secondary to voluntary increase in intra-abdominal pressure applied as bladder filling approaches the critical capacity.

The electromyograms in this patient following sacral nerve crush are in complete accord with the recent report of Corey and Vest,[8] who have demonstrated that the typical "A–B" wave complex in a variety of experimental animals can be elicited only by stimulation of the parasympathetic nerves or by administration of acetylcholine.

Reference should be made to a similar case reported in 1944 by Meredith.[19] His Case 2 had difficulty with his legs and bladder. At operation the tip of the conus medullaris seemed to be bound down by scar tissue at the lumbosacral level and freeing of the adhesions resulted in "recession cephalward of the entire cord." Postoperatively there was improvement in bladder function, apparent loss of anesthesia in the legs and increase in motor power of the legs.

In our case, the conus did not move upward when freed of adhesions and in fact the cord was well relaxed. The finding of a sharp rupture of the nucleus pulposus at the L4 interspace was felt not to have contributed to the production of cord signs or symptoms, although this possibility cannot be denied. It was our impression that crushing the S3 nerve roots effected the change in bladder function. There has been no change in the legs since operation.

Although this approach to bladder incontinence has been used in patients rendered paraplegic from other causes, it has not been reported as useful in cases of the defect termed myelomeningocele. This new technique may offer hope of bladder control in these patients with myelomeningocele who survive and are otherwise relatively intact. The value of the anterior colporrhaphy performed several months previously is difficult to assess. Possibly it has contributed to the success in bladder control following the crushing of the S3 nerve roots. The fact that it required several weeks for this individual to develop bladder control after crushing of the S3 roots would indicate that conclusions concerning alteration of bladder function by procaine block of various sacral roots might not be valid.

This particular method has apparently not been previously applied to a patient with a congenital defect of the spine and it is entirely probable that only a relatively small number of patients with such congenital defects would be amenable to such therapy. However, this approach to the problem in patients with myelomeningocele and urinary incontinence may in the future result in great improvement of bladder function in these individuals. It is most distressing in certain young people who are otherwise well and able to get about fairly adequately to see the social ostracism that results from constant urinary incontinence.

SUMMARY

1. An adult patient with urinary incontinence from a small myelomeningocele has been reported.

2. Operative findings included the tip of the conus medullaris at the lumbosacral level and a midline ruptured nucleus pulposus at L4, the latter apparently causing no encroachment on the cord.

3. Bladder continence has been gained since operation, apparently as a result of crushing of the S3 nerve roots, the only apparent efferent nerve supply of the bladder. It would appear that blockage of the abnormal parasympathetic outflow permitted a more effective coordination and mass contraction of the detrusor in response to physiologic filling of the viscus.

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SPEECH DISTURBANCES IN ASSOCIATION WITH PARASAGITTAL FRONTAL LESIONS*

J. G. CHUSID, M.D., C. G. DE GUTIÉRREZ-MAHONEY, M.D. AND M. P. MARGULES-LAVERGNE, M.D.

Neurological Division, St. Vincent's Hospital, New York, New York

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SINCE the classical descriptions of Broca,[5] Pierre Marie,[17] Wernicke[22] and Dejerine,[9] the area of the dominant cerebral hemisphere most intimately associated with the function of speech has been considered to be that part that centers about the lateral portion of the central (Rolandic) sulcus and the adjacent portion of the lateral (Sylvian) sulcus. Bouillaud[2,3] had previously stressed a relationship between the frontal lobes and motor speech and Auburtin[1] described an experiment on a patient of Cullerier in which light pressure with a spatula on the exposed frontal lobes caused an immediate interruption of speech during interrogation. Because of interest in language disorders associated with lesions of more medially situated areas of the dominant hemisphere, we have assembled data that bear upon this subject.

Parasagittal meningiomas may be associated with language dysfunction of variable degree. In 1879 Magnan[16] reported the case of a 61-year-old woman, who, he stated, "was unable to give any account of herself. She pronounced words or monosyllables without connection, and could not name objects. She reflected, tried, became impatient, wept occasionally, but was unsuccessful; but occasionallly she hit upon the right name, on which her countenance expanded, and she seemed pleased at her success. She had the irritability, sensibility and mobility of aphasics, generally." She had a right hemiplegia and "having a cardiac affection so it was natural to suppose embolism and softening of the third frontal convolution on the left side, the insula, corpus striatum and deep parts. On post mortem quite a different affection was actually found." The calvarium was adherent at the vertex and there was an osseous elevation at the posterior part of the left frontal and anterior part of the parietal bones on the inner side. Reflection of the dura mater disclosed a tumor "inserted in the internal aspect of the dura mater." The tumor projected into the posterior half of the first two frontal convolutions and the upper two-thirds of the ascending frontal. "Notwithstanding the immediate proximity of the tumor, the cortex of the third frontal had not been softened." The tumor was composed of considerable connective tissue with fusiform cells in some places, and in others polygonal

* Presented at the 19th Annual Meeting of the Harvey Cushing Society, April 27, 1951, Hollywood, Florida.

cells with one or more nuclei and only traces of connective tissue. The diagnosis was "neuroglia sarcoma" of the frontal lobe.

Elsberg[10] in 1931 stated "Parasagittal meningiomas over the left cerebral hemisphere, even if not large, sometimes produce definite disturbances of speech, either a sensory or motor or mixed type of aphasia. . . . The growths are often not large enough to make direct pressure upon the areas in which the centers of speech are supposed to lie, nor is the intracranial pressure seen at the operating table sufficiently high to permit one to predicate a diaschysis in von Monakow's sense."

In the Cushing and Eisenhardt[7] monograph on meningiomas, there are noted 7 instances of left parasagittal meningiomas (Cases 16, 25, 28, 30, 36, 37 and 51) occurring in right-handed individuals in association with speech disturbances. A review of the records in these cases, all of which were from Dr. Cushing's service at the Peter Bent Brigham Hospital in Boston, was made and the following pertinent data were abstracted:

Case 16. S.S., a woman aged 41, had severe headaches for 3 years with failure of vision, blindness, and weakness of the right arm and leg. She spoke no English and the history was obtained through her husband.

The following notes were made regarding her speech. "Patient apparently has an aphasia of moderate degree, husband stating that patient often uses the wrong words." Dr. Horrax noted "the husband is also very sure that the patient's speech has been affected." A month after admission, the husband observed that the patient's speech had become distinctly poorer and he found great difficulty in understanding her.

Operation was carried out in two stages. At the first, a left temporal bone flap was reflected and at the second session, the area exposed had to be enlarged with rongeurs. A 60 gm. parasagittal meningioma was removed which, from Dr. Cushing's sketches, would locate it in a position straddling the fissure of Rolando at the midline (Fig. 1).

Case 25. C.J.T., a 48-year-old lady, complained of paralysis of her right side and inability to talk. For 15 months she had had headache and had become dull mentally. Convulsions involving the right arm and leg had occurred for about 10 months. She became drowsy, cerebrated slowly and her memory failed. She also had much difficulty talking.

She had bilateral papilledema, right hemiparesis and there was no apraxia. "Patient is very slow in all her answers. She knows the month, the day and the date and what hospital she is in. She is able to name all the objects in the room excepting the electric lamp. She could not get the name for that. Also, in general conversation, it is apparent that at times she has great difficulty in finding the right word. She does not mispronounce words or use wrong words." Her husband also noted that "for the past 2 months she has had difficulty in finding the right word at times." He thought that she understood perfectly everything that was said to her.

The tumor measured 8.5 cm. in length and extended fairly well forward of the fissure of Rolando and half of its bulk was anterior to the dividing line between the frontal and central thirds of the longitudinal sinus. The tumor weighed 162 gm. and was removed in a two-stage procedure (Fig. 2).

Toward the end of the operation she kept repeating "I want to" and many attempts were made to supply the blank, asking if she wanted a drink, etc., but

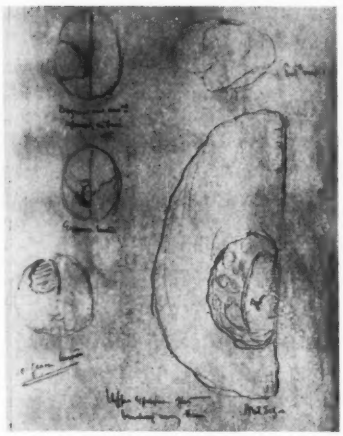

FIG. 1

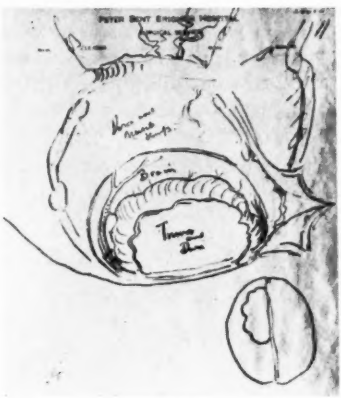

FIG. 2

shortly afterwards she said "I want to get well." Because of her difficulty with speech during the procedure, a running series of notes was made about her speech for a period of 4 hours after operation. A few days afterwards it was noted that she pronounced her words well but she had occasional difficulty in getting a sentence started although it was evident she knew what to say. A week after operation it was observed that there was "no aphasia."

Case 28. P.F.D., a man aged 42 years, complained of failing vision, dizziness and headaches for about 5 months. His family had also noted slowness and failure of his memory, but on examination he had difficulty in understanding what was said to him and questions had to be repeated before he understood. He answered slowly, with some difficulty, and often paraphrased. He avoided nouns. In attempting to explain the difficulty he had in talking, he said "I—I don't know, I don't seem to have the same track twice." He had no definite anomia although he had to stop and consider before giving the name of objects. Dr. Horrax noted "very marked difficulty in calculation and some hesitancy for words," and subsequently said "the speech disturbance and mental symptoms are the only things of any localizing significance in this case."

A left frontal parasagittal meningioma was removed by Dr. Horrax (Fig. 3).

A week after operation there was "very marked improvement in speech which patient himself recognizes." Three weeks after operation he "has a slight hesitation in talking from time to time and gropes for phrases rather than for words."

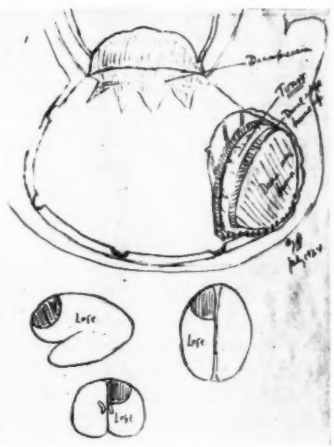

FIG. 3

Case 30. B.K., a lady aged 26, complained of failing vision, had headaches for 8 years, weakness of the right leg for 1 year and "about 1 month ago she became conscious of the fact, particularly at some times more than others, that her tongue felt thick and large and speech was slow. She wishes to talk rapidly but can talk only slowly." She had papilledema, right facial weakness and answered questions quite definitely slower but no aphasia was demonstrable.

A ventriculogram disclosed a "tumor of the left hemisphere depressing the ventricles." A left parasagittal tumor straddling the junction between the frontal and central thirds of the longitudinal sinus was removed (Fig. 4).

FIG. 4

On the following day she was able to answer only by "yes" and "no." She indicated that her speech was limited to this extent. A fortnight after operation (2nd stage): "speech still hesitant; difficulty in finding words." A month after the 2nd-stage operation, Dr. Leo Davidoff noted "quite marked aphasia, anomia and inability to express self in adequate language."

Case 36. W.H.B., a 31-year-old man, complained of weakness of the right side and convulsions of the right arm and face of 3 months' duration. For 2 months he had had intermittent difficulty finding words to express himself. He knew what he wanted to say but the words uttered did not make sense and had no connection with his thoughts. If he talked slowly and took a great deal of time about it, he could make simple things intelligible. Subsequently he had a convulsion and "his motor aphasia was even more marked and he found that he could see a newspaper but the words did not mean anything to him."

Examination disclosed weakness of the right upper extremity, early papilledema and some difficulty in finding words to express his thoughts. He had to speak slowly to have his sentences make meaning. Dr. Fulton noted "patient speaks slowly, occasionally seems to have difficulty in finding the word he wants. Names simple objects such as button, pen, nose; became a little confused when asked what his sister's children's names were. Smiles in a rather vacant way when questioned but does not seem particularly troubled or self-conscious on account of his disability. Says that he has not been able to follow the thread of stories and cannot seem to appreciate what he reads in newspapers. Cannot write with right hand, says he can hold a pen but it will not percolate."

FIG. 5

Dr. Cushing removed a large frontal parasagittal meningioma (Fig. 5).

After the operation the patient had to fum-

ble considerably to express himself. Commands had to be repeated two or three times before he comprehended and obeyed. About a month after operation, his speech was adequate for conversation. "Abstractions were still poorly handled. He was alert and intelligent but verbal mentation was slowed."

Case 37. D.W., a 54-year-old lady, complained of convulsions involving the left arm and left leg for a period of a few months, headaches and blindness. She had some confusion "particularly in talking and finding names." Her speech disturbance included difficulty in comprehending what she said although she understood other people perfectly well.

Examination disclosed definite anomia and she confused somewhat similar sounding names of dissimilar objects. Sometimes anomia and aphasia were marked symptoms. There was bilateral papilledema of 4 D. The strength of the right side was better than the left; all reflexes were brisk; both plantars were extensor and the x-rays demonstrated increased vascularity in the left frontal bone.

Dr. Cushing removed a left frontal parasagittal meningioma (Fig. 6).

FIG. 6

Two years after discharge she died at a psychopathic hospital and postmortem examination disclosed a bilateral parasagittal meningioma limited to the frontal poles and about as large on one side as the other.

Case 51. J.O., a 30-year-old man, complained of right-sided weakness, failing vision, headache and vomiting of 9 months' duration. "For three to four months it had been embarrassing to him to discover that he was unable to get words out. He believes that he has never miscalled objects or people, but many times has difficulty in saying the things he wants to say, and at times, gets words twisted, always being aware of this himself however. He has had no difficulty in understanding written or spoken words."

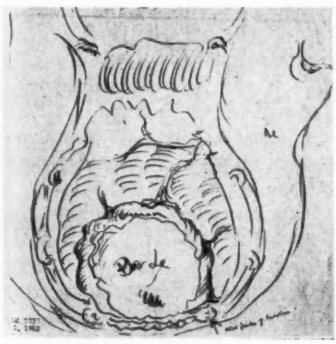

FIG. 7

Examination disclosed bilateral papilledema, right homonymous hemianopia, right hemiparesis and paraphasia. "Aphasia is not easily elicited on examination although there is a definite history which is almost conclusive. He has no true anomia, no alexia, no apraxia. He is unable to write because of the paresis of the right hand. In giving an account of his present illness he frequently, however, gets words mixed up, particularly the names of things, but immediately discovers the defect and sets about correcting it."

Dr. Cushing removed a large parasagittal meningioma from the frontal region which extended back just beyond the central fissure (Fig. 7).

About 3 weeks after operation, it was noted that he had "much less speech hesitancy" and a little later Dr. Bronson Ray noted "aphasia very slight now."

The following 2 cases of parasagittal meningioma were studied on the Neurological Division of St. Vincent's Hospital, New York.

Case L.R. A 30-year-old man was admitted to hospital on Nov. 24, 1948. He had had a convulsion 2 months previously after which he had speech difficulty of a very transitory nature which occurred 2–3 times a day for about a fortnight. Subsequently, this became more noticeable and he had difficulty forming words and sentences. A month before admission the right lower extremity became weak and shortly thereafter the right upper extremity was involved. He then had seizures involving the right side of his body.

Examination disclosed a right hemiparesis. He was left-handed; his mother was left-handed and his sister was ambidextrous. He had no very striking speech disturbance other than some hesitancy but no difficulty naming objects. An EEG revealed left frontal focal slowing, most intense near the midline. A ventriculogram disclosed a depression and shift of the anterior part of the left ventricle toward the right.

At operation on Dec. 1, 1948, a tumor mass, 3×3 cm., weighing 30 gm. and situated along the falx, was removed from the left posterior frontal lobe in the paracoronal area. The tumor was a highly malignant type of meningioma.

After operation there was a striking motor aphasia. This case was of interest not only because of the situation of the neoplasm, but also because of the occurrence of a speech disturbance in a left-handed individual of left-handed stock, the lesion being in the left hemisphere (Fig. 8).

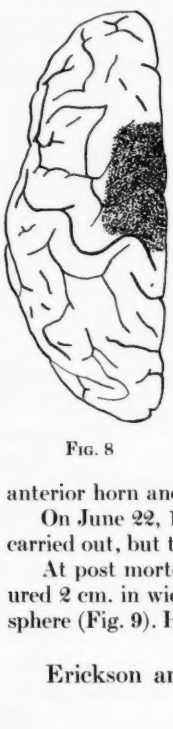

FIG. 8

Case O.R. A 51-year-old lady was admitted to the hospital as a patient of Dr. J. T. Daniels on May 28, 1948 because for 3 months she had had weakness of the right side, difficulty in thinking clearly, and stammering. Her doctor wrote "The presenting difficulty according to the patient's diary was a sudden change in legibility of her handwriting. This was followed by semantic and syntactic aphasia, later including a nominal defect of speech."

Examination disclosed a right hemiparesis, mental inaptitude and a disturbance of naming objects. There was hyperostosis of the skull in the coronal region over the midline. An EEG disclosed a left frontal slow wave focus and a pneumoencephalogram revealed a shift of the ventricular system to the right, the anterior horn and body of the ventricle being displaced downward to the right.

On June 22, 1948, partial removal of a left frontal parasagittal meningioma was carried out, but the patient failed and expired on June 24, 1948.

At post mortem the tumor obliterated the longitudinal sinus completely, measured 2 cm. in width and 5 cm. in length and extended over into the opposite hemisphere (Fig. 9). Histologically, it was a meningioma.

Erickson and Woolsey[11] reported focal epileptiform seizures beginning

with intermittent vocalization, reminiscent of that produced in other patients by stimulation of the "supplementary motor area," in a patient with a small paracentral meningioma compressing the supplementary motor area. For 3 days after operation this patient had "a slight motor aphasia." They described 2 additional patients with bilateral frontal parasagittal ("saddle-bag") meningiomas just rostral to the precentral gyrus, both of whom had profound motor aphasia. Sweet[21] described the findings in a patient with a meningioma lying at the junction of the falx and the superior lateral surface of the dura mater, just ahead of the rolandic motor cortex. "This meningioma was so small it did not produce any increased intracranial pressure, nor was there any distortion or displacement of the lateral ventricle in the pneumo-encephalograms. . . . Seizures began with sudden inability to say what she wanted to say and instead she would simply say "I, I, I, I, I, I." This would end after a few seconds and the patient would then be able to speak properly. On a few occasions this type of seizure was followed by a typical generalized convulsion."

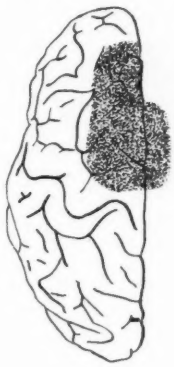

FIG. 9

Intrinsic tumors of the medial portion of the dominant cerebral hemisphere may also be associated with clinical evidence of language disturbance. In 1882 Hughlings Jackson[14] described the case of an adult male, subject for many years to occasional seizures starting in the right foot, in whom a tumor of the medial portion of the left cerebral hemisphere was ultimately found. At one phase, he mentioned that the patient's "fits began by inability to talk, probably aphasia." On one occasion he was unable to speak for three minutes and a half, but no spasm was noted; the patient, however, felt "twittering" in his right toe. Hess[12] scrutinized 245 cases of hemispheric tumors for "misleading" neurological signs and distant electroencephalographic slow wave foci. Two thirds of the "false" clinical signs occurred in cases of left-sided lesions; "false" clinical signs were found in one-quarter (61 cases), one-eighth belonging to the aphasic syndrome.

Experience with the following cases of metastatic carcinoma prompted the present study. The patients were both right-handed and were studied on the Neurological Division of St. Vincent's Hospital, New York.

Case R.B. A 50-year-old man had had a pneumonectomy for carcinoma of the lung performed about 9 months prior to admission. Two weeks before admission he told his wife he had trouble writing at work. His wife stated that about 10 days prior to admission his speech was "confused" and "did not make sense." A few days before admission he was found unconscious on the floor, following which weakness of the right upper extremity was apparent.

Examination disclosed a right-sided hyperreflexia, right extensor plantar response and a marked mixed aphasia. On occasion he could repeat phrases that he heard, could follow simple commands and answer simple direct questions. The EEG disclosed a left frontotemporal slow wave focus.

A large frontotemporal bone flap was reflected and a metastatic tumor, 4×5 cm. in size, situated close to the midline in the frontal region (Fig. 10), was enucleated. At postmortem examination 5 days later no other metastatic or gross lesions of the brain were present.

Case E.G. A 57-year-old man had speech impairment of about 3 weeks' duration, parietal headache, failure of memory and change in personal habits. His wife characterized the alteration in speech as one in which the patient's "conversation became less and less" and finally reached a "yes or no" stage about a week before admission. He apparently could not comprehend what he read at this time. A few days before

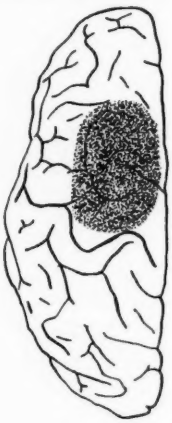

FIG. 10

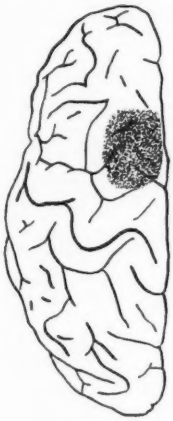

FIG. 11

admission he said without apparent reason "I went to the . . . Paper Company and did very good, very good, very good."

Examination disclosed right facial weakness, right extensor plantar response and right hemiparesis. He could name objects correctly, carried out simple commands, and could identify persons properly. He could read aloud, but could not comprehend the contents of what he had read. The EEG disclosed a frontal slow wave focus most intense near the midline.

Following ventriculographic studies, a left frontoparietal bone flap was made with extirpation of a metastatic tumor of the frontal lobe (3×2×1 cm.) near the midline (Fig. 11).

Postoperatively he was completely aphasic for several days, but gradually improved thereafter. At autopsy 7 months later there was no evidence of other metastases to the brain; a hypernephroma of the kidney was present.

Lesions of the dominant cerebral hemisphere associated with occlusion of the anterior cerebral artery may be associated with significant language disorder. Liepmann and Maas[15] reported the case of a 70-year-old diabetic man with onset over a 24-hour period of a right hemiparesis and inability to speak. After a few weeks, he made attempts to speak, but his speech was not clear. He could repeat single letters as well as words. Reading aloud of

single letters was undisturbed, although he made a few mistakes on reading several words. Because of the right-sided paralysis, an attempt was made to have the patient write with the left hand, but spontaneous and dictated speech could not be written with the left hand. At postmortem examination there was softening in the distribution of the left anterior cerebral artery from the frontal to the paracentral region, involving also the left half of the corpus callosum. Critchley[6] mentioned that speech defects of various types, usually transient, may occur with left-sided anterior cerebral artery lesions and characterized these as being defects partly of an aphasic order and partly dysarthric. Hyland[13] reported the case of a 61-year-old woman with thrombosis of the common trunk of an anomalously distributed anterior cerebral artery which divided into two branches at the dorsum of the corpus callosum, in whom aphasia was a prominent sign. Davison, Goodhart and Needles[8] remarked that aphasia, generally temporary, if encountered in cases of anterior cerebral artery lesions "is due to edema or pressure." Poppen[19] mentioned the presence of aphasia following left anterior cerebral artery ligation during surgery in the last 2 of 10 cases he reported. In his Case 9, a large meningioma of the left frontal lobe attached to the anterior portion of the falx at the level of the genu of the corpus callosum was removed and the left anterior cerebral artery was ligated. After this there was "complete aphasia," which disappeared and was considered to be "no more than that observed after a left craniotomy in which considerable edema occurs owing to necessary manipulations of the brain." In his Case 10, a metastatic carcinoma attached to the lower margin of the falx and the anterior cerebral vessels was enucleated and the main trunk of the left anterior cerebral artery was ligated. Postoperatively the patient was aphasic and was "still somewhat aphasic" 2 months later.

From clinical neurophysiological studies there are indications that the medial portion of the dominant cerebral hemisphere may play a part in speech. In 1940, Brickner[4] reported the findings upon electrical stimulation of the mesial cortex of the left cerebral hemisphere in a 32-year-old right-handed woman with a history of major and minor seizures since the age of 17 years. At operation, during routine cortical exploration, an area approximately 1 cm. in diameter was discovered "accidentally" which was low down in area 6 (Brodmann), at its junction with the posterior superior portion of area 32, which on stimulation caused the patient to utter, in a stereotyped manner, syllables resembling "err, err, err." When the patient was asked to say the alphabet and an electrical stimulus was applied to this area, repetition of the syllable last spoken occurred for the duration of the stimulus, following which the continuation of the alphabet was immediately resumed. The letters repeated were slightly distorted and their rate of production was slightly slower than the rate at which the patient recited the rest of the alphabet. The patient stated she was fully aware of what was happening, but could not check herself. Histological study of the area disclosed no abnormalities.

Smith's[20] studies on electrical stimulation of the rostral cingular cortex of monkeys indicated that vocalization response, identical to that made by the animal under the usual conditions of laboratory existence, can occur. At times the "vocalization" appeared as part of a complex reaction characterized by opening of the eyes, dilatation of the pupils and vocalization. Movements of the facial muscles, usually bilateral, often accompanied the vocalization with protrusion, rounding or retraction of the lips. While a low-pitched gutteral sound was the one most frequently obtained, there occurred at times, cries, soft and plaintive, such as the animal makes at feeding time. While ordinarily such vocalization response occurred only upon electrical stimulation of the rostral cingular zone, it was noted that after the production of vocalization, the immediate excitation of the cortex above the cingular gyrus also resulted in a vocalized response.

Penfield and Rasmussen[18] reported "arrest of talking" on stimulation of the most medial portion of the convexity of the cerebral hemisphere in the region of area 6, or of the supracingular zone of the paracentral lobule. They stated:

"Two bilateral cortical areas of vocalization, Rolandic and superior frontal, have been demonstrated in man. Electrical stimulation of either of these areas, in either hemisphere, may produce vocalization or it may produce arrest of speech. The difficulty in speaking applies to all words alike. In no case yet observed has it produced aphasia in these areas." [*p. 106*]

"More recent cases suggest that inactivation of the superior frontal zone within the longitudinal fissure on the dominant hemisphere is capable of producing aphasia." [*footnote p. 107*]

"A part of the mesial surface of the superior intermediate frontal region is occupied by the supplementary motor representation in which is included bilateral synergic movement and vocalization. Removal of this area in the nondominant hemisphere alone produces no specific deficit that we have detected as yet. Removal on the dominant side alone has also been carried out in its anterior portion without obvious clinical sequel." [*p. 199*]

"We have only once removed the area all the way to the precentral gyrus within the longitudinal fissure on the dominant side. That patient (D.T.) became speechless during the ablation of this final posterior portion. He died of pneumonia a week later without having spoken again, and autopsy showed no obvious cause of this speechlessness." [*footnote p. 199*]

Our study suggests that disorders involving language function may occur in conjunction with lesions of the medial portion of the dominant cerebral hemisphere. Varying degrees and types of speech disturbance as well as convulsive seizures characterized by vocalization have been encountered. In some tumor cases improvement in language function occurred after operation; in vascular cases remission was sometimes noted after recovery from the acute episode. Although the electrical stimulation studies reported by Brickner, Smith, and Penfield and Rasmussen serve to establish a possible neurophysiological basis for language disorder associated with lesions of the medial aspect of the dominant cerebral hemisphere, the presence of associ-

ated defects dependent upon involvement of the classically recognized cerebral language areas cannot be excluded as a factor in some of the cases reviewed. This is obviously true in tumor cases, in which altered circulation, mechanical displacement and compression, edema and related pathological changes are not unusual. However, the uncritical dismissal of all language disorders encountered with lesions of the dominant cerebral hemisphere purely upon such a basis is unwarranted, since language disturbances have also occurred in cases of small parasagittal lesions in which remote tissue changes were not found.

SUMMARY

1. Impaired language function of varying degree and type and convulsive seizures characterized by vocalization may occur in patients with lesions of the medial portion of the frontal lobe of the dominant cerebral hemisphere.

2. The clinical features of 11 cases in which disturbed speech occurred in association with parasagittal tumors are presented and similar findings in other reported cases are cited.

3. Reports of language disorders after interruption of the anterior cerebral artery of the dominant cerebral hemisphere are noted.

4. Electrical stimulation studies of mesial cerebral cortex suggest a neurophysiological basis for language difficulties associated with lesions of the medial portion of the dominant cerebral hemisphere.

The authors are indebted to the Brain Tumor Registry of Yale University for the opportunity to review the original records of Dr. Cushing's cases and to reproduce his operative sketches.

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CASE REPORTS AND TECHNICAL NOTE

CHOROID CYST OF BRAIN WITH LEUKEMIC CONTENTS IN A PATIENT HAVING LEUKEMIA

DAVID J. LAFIA, M.D.,* AND GILBERT HORRAX, M.D.
Department of Neurosurgery, The Lahey Clinic, Boston, Massachusetts

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The lesion to be reported is unique so far as we are aware. In his series of 2,000 intracranial tumors Cushing did not mention such a condition, and during the past 35 years one of us (G.H.) has not encountered a similar case. In our registry of brain tumors we have called it a "leukemic" cyst, but this designation is doubtless incorrect, since the cyst was of choroidal origin, but its content was entirely leukemic material with the general appearance of ordinary milk.

Leukemic processes in the central nervous system are well known. Whether they occur as primary lesions, favoring the multicentric theory of leukemia, or as secondary, invasive lesions, we cannot say. In the literature most cases described are part of the terminal picture of leukemia. Diamond[1] studied the brains of 14 patients who died of this malady. In 7 histories he found no clinical evidence of neurological disorder, yet all had histologic changes in the nervous system characteristic of leukemia, namely, infiltration of myelocytes (1) around and within blood vessels, (2) in subarachnoid spaces, (3) within brain parenchyma both circumscribed and diffuse lesions, (4) rarefaction and vacuolation of neurons and axons, and (5) proliferation of oligodendroglia. Such pathological changes produce a variety of symptoms and signs, usually suggesting diffuse instead of focal disease. Focal fits, however, were reported by Hellich[2] in a patient 3 to 4 months after a diagnosis of leukemia was made. The brain in this case showed parenchymatous infiltration of leukemic cells in the cortex and thalamus.

The case here reported deserves attention because the clinical course was that of a brain tumor in the pararolandic area. However, the high leukocytosis with myelocytes on routine blood count was diagnostic of myelogenous leukemia. The extracortical cyst in the rolandic area found at craniotomy is apparently most unusual for leukemia. Histologically, the wall of the cyst was lined by tall, ciliated columnar cells instead of the expected glial tissue. This pointed to a papillary adenocystoma of choroidal origin. It is not easy to explain this finding as most choroidal cysts originate in or near the ventricular system. Since leukocytes and myelocytes crammed the cyst cavity, it is possible that leukemic cells infiltrated a congenital choroidal "cell rest," causing its growth until signs of a space-consuming lesion developed.

REPORT OF CASE

F.B., a 20-year-old white male, was admitted on Oct. 4, 1934, complaining of spells of unconsciousness of 9 months' duration. He had been relatively well until January 1934

* Former Fellow in Neurosurgery, The Lahey Clinic. Present address: 187 Waterman Street, Providence, Rhode Island.

when his first seizures began. There was an aura of tremor with twitchings of the left hand. This was followed by clonic spasms of the left arm and leg, proceeding to generalized convulsions with loss of consciousness. After the seizure the patient's left hand felt "queer" and weak. He had had a total of nine seizures in the previous 9 months. Two months before admission he became excessively irritable and somnolent. He took prolonged afternoon naps, although he slept as much as 10 hours during the night. About 1 month prior to admission his left hand and leg became weak.

Neurological Examination. Bilateral papilledema of 2 D. was present with normal fields on confrontation and perimetry. There was moderate loss of strength in the left hand grip. Reflexes were more active in the left arm and leg; there were no abnormal reflexes. A roentgenogram of the skull revealed an area of decreased radiodensity in the right frontal and central zones. The sella turcica was intact. In the course of routine blood studies a white blood cell count of 53,000 with 18 myelocytes was noted. The medical consultant found an

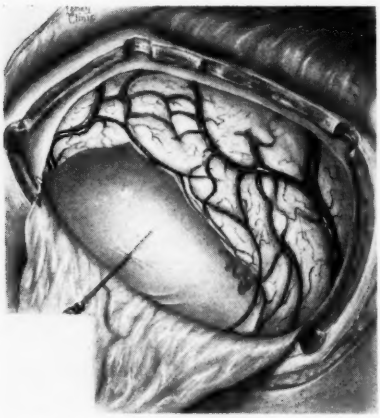

FIG. 1. Appearance of cyst when exposed at operation.

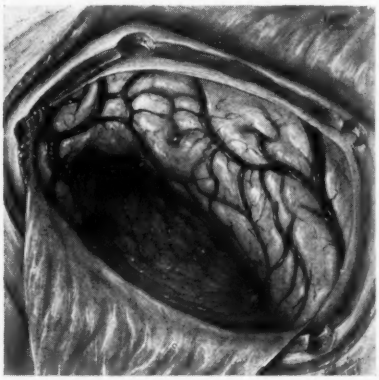

FIG. 2. Cavity remaining after evacuation of cyst and removal of cyst wall.

enlarged spleen on physical examination, and he made a diagnosis of chronic myelogenous leukemia.

1st Operation. Despite the presence of leukemia there remained the possibility of a non-associated tumor. On Oct. 8, 1934, a pneumoventriculogram was made and showed downward displacement of the central portion of the right lateral ventricle with a shift from right to left.

Under local anesthesia a right frontoparietal bone flap was reflected, exposing a large cystic mass near the midline of the rolandic area. To quote from the surgeon's notes: "A rather cystic area could be felt through the dura mater near the midline and in the center of the exposed region. The dura was incised with the pedicle at the midline and upon reflecting it a large cystic lesion was seen involving the cortex near the midline immediately in the rolandic area. The cyst wall was rather thin and translucent, filled with an opaque grayish white fluid (Fig. 1). The lesion was different from those seen by any of the operative team. . . . The cyst was then evacuated by suction through a needle attached to a syringe, approximately 60 cc. in all being obtained. A smear disclosed pus cells and myelocytes. A cell count of the fluid showed 1,918 white blood cells with 13 myelocytes per c. mm. The question, of course, arose whether this was due to a leukemic condition or an abscess. The entire cyst wall was carefully removed and stripped from the cortex fairly readily" (Fig. 2).

Pathological Report. The diagnosis of the cyst wall was adenocystoma, papillary type, of choroidal origin. The pathologist, Dr. Shields Warren, reported that the fluid removed from

the cyst was compatible with leukemia. A culture taken from the fluid at operation showed no growth after 3 days.

A further study of this cyst wall was made by Dr. S. J. Hicks. He reported as follows: "There are atypical mononuclear cells in the blood vessels of the cyst, and there are similar cells incorporated in some clotted material adherent to the lining of the cyst. These may certainly be interpreted as leukemic cells and represent some remains of the cyst content."

Course. The postoperative course was somewhat stormy. Although the patient aroused and was able to move the left side, the area over the bone flap swelled and was palpably riding.

2nd Operation. On Oct. 11, 1934, because of slowing pulse and increased drowsiness, the bone flap was elevated and a large extradural hematoma was removed.

Course. The patient rallied and, except for three persistent draining sinuses in the skin flap, his recovery was satisfactory. The leukemia caused these complications, predisposing to faulty blood clotting and lessened resistance to infection. After the 2nd operation the white blood cell count rose to 85,000. Fowler's solution was given, and by Nov. 7, 1934 the blood count dropped to 15,000. The draining sinuses granulated and at discharge (Nov. 9, 1934) the patient was ambulatory but the left side was weak. Seizures were controlled fairly well with sodium phenobarbital.

2nd Admission, June 27, 1935. Since his discharge the patient had had intermittent left-sided focal seizures followed by generalized convulsions. The wound was draining and he was febrile. Roentgenograms of the skull showed a moth-eaten appearance of the bone flap, indicating osteomyelitis.

3rd and 4th Operations. On June 29, 1935, the bone flap was completely removed and the area was left adequately decompressed. The skin flap bulged increasingly; so on July 3, 1935 it was reflected and a huge extradural clot was evacuated. After this the skin flap was partially resutured and a pressure dressing was applied.

FIG. 3. Photomicrograph of cyst lining to show tall ciliated columnar epithelium (×500).

Course. The wound finally healed. The white blood cell count at this time was 120,000 with a great number of myelocytes. The spleen was palpable several fingerbreadths below the costal margin. Roentgen therapy was given to the long bones, and at the time of discharge on July 21, 1935 the white blood cell count had dropped to 7,750.

The course of the patient was followed at home by Dr. Malott of Scottsbluff, Nebraska, who reported that the patient had seizures, although less severe.

3rd Admission, April 1, 1936. Because of seizures and paresis of the left arm and leg, progressive debility, and a white blood cell count of 165,000, the patient was readmitted.

Neurological examination disclosed moderate weakness of the left arm and leg with hyperactive reflexes; the optic disks were not elevated. The leukemia was manifestly advanced.

After roentgen therapy the white blood cell count dropped to 7,000. The patient regained his strength and left the hospital on April 6, 1936.

Course. From April to July, 1936 the patient had three seizures. He was back at work. When seen at the Lahey Clinic in July 1936 the findings were unchanged from the previous examination. The white blood cell count was 14,850. Dr. Malott, on Oct. 29, 1936, reported that the patient had died. The course of events leading to his death was typical of leukemia. Until his death he had had an occasional left-sided seizure.

Autopsy Findings. The autopsy was done by Dr. Malott who removed the organs and sent them to the Pathological Laboratory of the New England Deaconess Hospital. On removing the brain Dr. Malott noted that the posterior portion of the resection was filled with approximately 2 ounces of grayish-green pus. The organs were examined by Dr. Shields Warren who reported changes characteristic of chronic myelogenous leukemia in the spleen, lymph nodes and bone marrow. The report on the brain was as follows: "Convolutions of the right hemisphere normal except in the right frontoparietal region where there is a large cystic space 4 by 3 by 3 cm. which appears to be lined by choroid membrane. No other abnormalities are noted. The histological section of this cortical cyst showed it to be lined by a single layer of tall, ciliated, columnar and flattened fusiform epithelium supported on a delicate basement membrane (Fig. 3). Small blood vessels scattered through the brain are partially filled with leukemoid cells." Dr. Warren's diagnosis was cortical cyst or papillary adenocystoma of choroid origin.

SUMMARY

Circumscribed infiltration of the brain with leukemic cells is rare compared with diffuse infiltration of the subarachnoid spaces and the epidural spinal spaces. In his series of 2000 intracranial tumors Cushing reported no such case. The lesion here reported is that of a choroid cyst containing leukemic material in a patient having chronic myelogenous leukemia, whose illness was ushered in with left jacksonian seizures. After craniotomy and removal of a cyst in the right rolandic area, followed by roentgen therapy, the patient survived 2 years.

We are greatly indebted to Dr. Shields Warren and to Dr. Samuel J. Hicks for their painstaking study of the pathological material from this patient.

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ANEURYSM OF COMMON CAROTID ARTERY IN THE NECK

FOLLOWING PARTIAL LIGATION FOR AN INTRACRANIAL ANEURYSM

SIDNEY W. GROSS, M.D., AND ABRAHAM HOLZMAN, M.D.
Neurosurgical Service, Montefiore Hospital, New York, New York

(Received for publication October 2, 1953)

There is still considerable controversy regarding the treatment of aneurysms of the circle of Willis.[3,9,10] Nevertheless most surgeons who have had experience in this field employ carotid ligation, either as a definitive method or as an adjunct to intracranial procedures.[2,4] It is not our purpose at this time to discuss the relative merits of the various methods of treatment of intracranial aneurysms. The following case illustrates an unusual complication of ligation of the common carotid in the neck for an aneurysm of the circle of Willis.

CASE REPORT

H.L., a married white woman of 25, collapsed while walking in the street. She was taken by ambulance to the emergency ward of a city hospital. On admission, she was in deep stupor, and there was a hematoma in the right occipital region. The patient improved during the next few hours and she was transferred to our care.

Examination about 24 hours later disclosed a thin woman in stupor. She could be roused with ease. She was confused and disoriented. The neck was moderately rigid, and there was a positive right Babinski.

Course. During the next 3 days the patient became more alert and less confused. The cerebrospinal fluid was grossly bloody. The initial pressure was 320 mm. On the 7th day ptosis of the right upper eyelid developed. Two days later there was a complete internal and external right 3rd nerve paralysis. The right pupil did not react to light and was widely dilated. The fundi showed beginning papilledema.

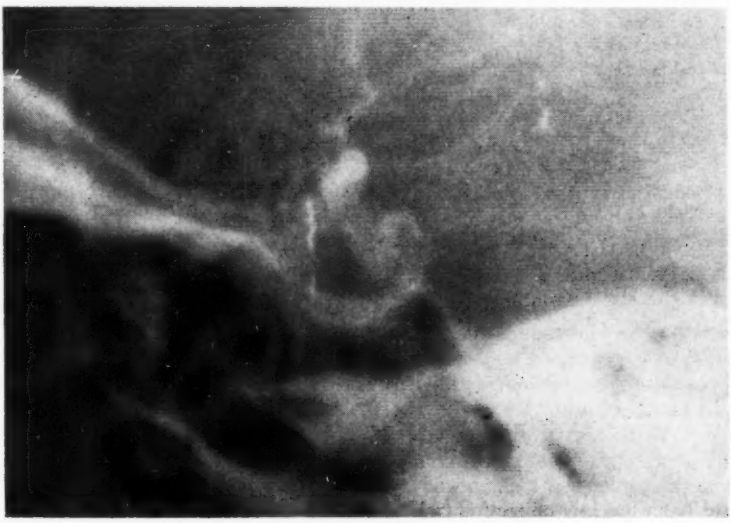

FIG. 1. Angiogram showing berry aneurysm springing from the internal carotid artery just above its junction with the posterior communicating artery.

Daily digital compression of the common carotid artery was started. The patient complained of light-headedness at first, but after a few days she could tolerate 10 minutes of compression without symptoms. At this time right carotid angiography was done with 35 per cent diodrast by the percutaneous technique. This disclosed a berry aneurysm (Fig. 1) springing from the internal carotid artery just above the origin of the posterior communicating artery.

Operation. A few days later the right common carotid artery was exposed with the use of local anesthesia. Occlusion of the artery with a rubber tape caused a slight weakness in the left upper and lower extremities. The common carotid artery was therefore partially occluded with a heavy braided silk ligature. The lumen was probably reduced to one-fourth or one-fifth of its original size.

Course. Following this procedure the patient improved rapidly. Within a few days the ptosis was much less evident, and the internal rectus palsy had also diminished. She was permitted to go home 3 weeks after the incomplete ligation. We had planned to re-admit her at a later date for ligation of the internal carotid artery.

FIG. 2. Specimen removed at operation showing silk ligature tied around the common carotid artery, aneurysm, and internal and external carotid arteries.

About 2 months after the partial ligation, the patient noted a small swelling in her neck at the operative site. Examination at this time disclosed a small mass, about 2 cm. in diameter, under the operative scar. A thrill and a bruit were present. There was slight weakness of the levator of the right lid, and an almost complete paralysis of the right superior rectus. The right pupil was slightly larger than the left and reacted to light sluggishly. The fundi were normal.

The patient was advised to re-enter the hospital; however, she postponed this for about 3 months. At this time the pulsating mass in the neck had increased in size slightly. The patient now tolerated compression above and below the mass in the neck without symptoms.

2nd Operation. On May 6, 1953, about 5 months after the initial partial ligation, under general endotracheal anesthesia the common carotid artery was exposed below the mass. The common carotid was imbricated with three arterial sutures, then doubly ligated with braided silk and divided. The aneurysm in the neck was then dissected from the surrounding tissues. The internal and external carotid arteries were then doubly ligated and divided. The specimen (Fig. 2) on removal measured 2.5×2×1.5 cm. Fresh blood clot was present in the aneurysmal sac.

Course. The patient improved rapidly following this procedure and she was discharged from the hospital 10 days later. She has remained well.

COMMENT

According to Halsted,[1] Antyllus, one of the great surgical figures of antiquity, was the first to describe a method for the treatment of peripheral aneurysm. Antyllus advised isolating the aneurysm between ligatures, then opening the sac with a small incision to empty its contents. This method remained in vogue until John Hunter (1728–93) advocated ligation high up in healthy tissues by a single ligature as the best method for the treatment of aneurysms.

Modern management of an aneurysm depends on its location, size, duration, etiology (spontaneous or traumatic), and age and condition of the patient. Pratt[2] listed the following methods: (1) Excision with end-to-end anastomosis. (2) Venous transplant. (3) Obliteration operation (Matas). (4) Occlusion by proximal ligation.

(5) End-to-end artery-vein anastomoses distal to aneurysm. (6) Extra-arterial irritation, with obliteration. (7) Wiring and coagulation.

To the above, one must, of course, add proximal and distal ligation with excision of the sac. This was the technique used in our case. Aneurysms of the common or of the internal carotid artery in the neck present a special problem because of the serious sequelae that may accompany the occlusion of these vessels.

Referring to carotid artery ligation, Matas[5] (1909) stated that the possible occurrence of cerebral disturbances "has invested the technically simple operation . . . with a gravity and anxiety that are associated with few other ligations." Reid[8] set forth certain principles governing the ligation of large arteries. He advocated that: (1) The size of the ligature should increase in direct proportion to the size of the artery; (2) the ligature should be tied during temporary distal and proximal closure of the artery to remove intra-arterial tension and thus avoid fracture of the media and intima; (3) the tension used in tying the ligature should be just enough to occlude the lumen; and (4) the ligature material should not be subject to stretch or dissolution. Reid cautioned against the use of partially occluding or crushing ligatures. When partial occlusion is indicated, he advocated the use of a flattened metallic band.

Our patient demonstrates an unusual complication of the partial ligation of a large artery with a round ligature. The mechanism by which the aneurysm developed seems simple enough. The media and intima were no doubt fractured when the ligature was tied. When symptoms and signs of cerebral ischemia developed, the ligature was loosened, resulting in a partial occlusion of the common carotid artery. With partial occlusion, atrophy of the injured arterial wall occurred with the development of a saccular dilatation of the lumen. In time the sac slowly enlarged forming a pulsating tumor mass at the site of ligation.

This case demonstrates the danger of partial occlusion of a large artery with a round ligature. Metal bands, special clamps and bands of fascia have been advocated for partial occlusion of the carotid vessel. However, in our experience, complications have occurred following the use of these methods also. In patients who tolerate total occlusion of the common carotid artery, we prefer to doubly ligate the vessel and divide it between the ligatures.[11] The artery is plicated before the ligatures are tied according to the method of Poppen.[6] When partial ligation is indicated, it is probably best to reduce the lumen of the artery by wrapping with fascia and maintaining the narrowed lumen by suturing the fascia in such a way as to form a tunnel at least one-half inch wide for the vessel to pass through. Metal bands and clamps left in place increase the hazard of infection with possible slough of the vessel wall. A simple and safe method for the gradual occlusion of large arteries has not yet been devised.

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SPONGE RUBBER PAD

FOR OPERATIONS PERFORMED WITH PATIENT IN PRONE POSITION

Robert E. Slemmer, M.D.

Department of Anatomy, University of Cincinnati College of Medicine, and Department of Neurosurgery, St. Mary's Hospital, Cincinnati, Ohio

(Received for publication July 27, 1953)

It is recognized that the prone position is not physiologic for operations and yet it is desirable to perform certain neurosurgical procedures in this position.

Provision must be made for the proper expansion of the chest and abdomen in order to avoid interference with respiration.

Several methods[1] for accomplishing this are in use. One consists of the use of shoulder supports attached to the head of the operating table. Another consists of the placement of sandbags beneath either shoulder. A third method is the use of a rolled pillow on either side of the body extending from the shoulder down to and including the crest of the ilium. A disadvantage of the latter method is the fact that it is difficult to maintain the pillows evenly so that the back is horizontal.

A foam rubber mattress seemed to be a possible solution to this problem. A window was cut in the mattress so that the patient's chest and abdomen could partially protrude through the opening thereby allowing normal respiratory movements of the chest and abdomen. In addition, it was found that the center piece could be used as a comfortable head rest. The mattress has been upholstered with a nonconducting cover so that it can be used in all situations where explosive anesthetic mixtures are used.

Uses. It is used on top of the standard operating table mattress and has been used for lumbar laminectomies, thoracic laminectomies, cerebellar procedures, and ventriculograms.

Fig. 1

Advantages. One of the advantages has been lessened bleeding. This is especially true when used for laminectomies and can be explained on the basis of diminished abdominal press with transferred pressure from the abdominal veins to the intraspinal veins.

Another advantage is the fact that uncomfortable pressure and redness can be avoided even when the patient is in the prone position for a considerable length of time.

A third advantage is the fact that because of the flexibility and compressibility of sponge rubber, the table itself can be adjusted either before or during the procedure without altering the general position of the patient on the table. To date no disadvantages have been observed.

Description of the Mattress. The mattress is the width of the operating table. The length is approximately three-fourths that of the operating table. The exact measurements (Fig. 1) are 38×20×3.5 inches. The opening is 22×10 inches. The center portion or cutout is constructed so that the opening corresponds approximately to the distance between the midthoracic region and the pubis. The sides of the opening are flexible enough so that they can be adjusted to the width of the patient.

Material. The standard sponge rubber (half mattress) can be obtained from any mattress manufacturer. It can be cut to the desired length and width. The opening also can be designed to suit the individual requirements. When not in use the center portion can be reinserted into the cutout for storage.

SUMMARY

An inexpensive pad which has proven itself to be of value when operating upon patients who are in the prone position is described. Its flexibility, uses, and advantages are discussed.

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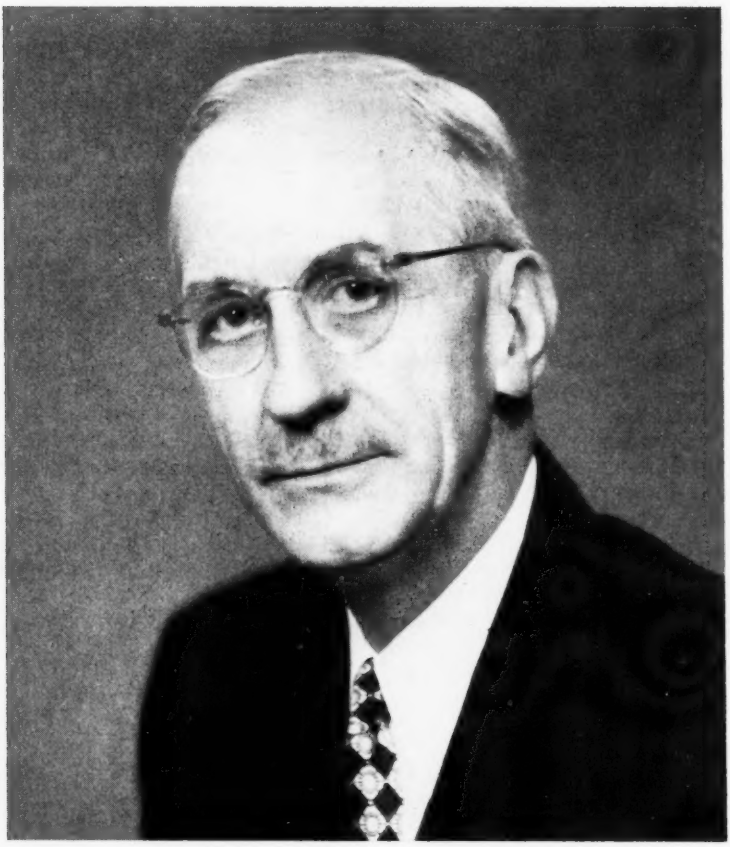
Obituary

FRANK RANDALL TEACHENOR
1888–1953



It is with sadness and regret that we speak of the passing of Dr. Frank Randall Teachenor who died suddenly November the twenty-eighth in Kansas City, Missouri at sixty-five years of age. He not only was one of the Middle West's first citizens, but his achievements were well known throughout Canada and the United States. His awards and honors were many, but they were always unsought by Doctor Teachenor, who was a quiet, retiring and kindly man. His only ambition in his work was to help his fellow man, and he was always reluctant to accept any degree of fame for carrying out his appointed task. His great understanding of human nature

and his endless devotion to his patients endeared him to the public and to the medical profession as well. To Doctor Teachenor each patient was a person and not a case history, and he was always deeply affected by their problems and by their suffering and sympathetically gave much of his own personal life towards the alleviation of the pain of those stricken and their families. He firmly believed in the principle of the Golden Rule, and at all times he practiced it and lived by it. This, in itself, is greatness.

Doctor Teachenor attended the University of Kansas School of Medicine, and following his graduation there in 1911, served for five years in training with Dr. Jabez Jackson. At this point his career was interrupted by the advent of the first World War, and he went into service with the Army and was stationed at Carlisle Barracks where he began his training in neurological surgery. While he was there he attended courses conducted by many of the country's leading neurosurgeons before being shipped overseas to serve with the Army in France. Upon his return to this country he was assigned to duty at Camp Dodge where he spent six months on peripheral nerve surgery. In 1920 he returned to Kansas City, Missouri, to establish the first practice of neurological surgery in an area extending between St. Louis, Missouri and the West Coast. In addition to his own practice, Doctor Teachenor undertook the difficult task of educating and training other men in this comparatively new field. His vision and efforts resulted in the establishment of facilities for teaching and research, and after years of unceasing work he had firmly integrated his specialty into the medical and surgical needs of the area. Much of what Doctor Teachenor learned had to be done the hard way by his own initiative in self-teaching and home study, and it was by this means and without formal training that he acquired an excellent knowledge of organic neurology. He was also a great believer in visiting other clinics to study the newer techniques developed by his colleagues elsewhere. All of this was not easy, and his perseverance and his wholehearted devotion to the goal he had set for himself were commendable. Certainly his community and the neighboring states have always been grateful for the tremendous vitality and generosity of this great pioneer.

He was a past President of the Jackson County Medical Society, the Western Surgical Society, and the Harvey Cushing Society. He was also a member of the Society of Neurological Surgeons and the Southern Medical Society and was the Professor Emeritus of Neurological Surgery at the University of Kansas School of Medicine. At the time of his death he was serving as the Vice-President of the Missouri State Medical Association. In the last World War he served in an advisory capacity on the committee for Selective Service for physicians, dentists and veterinarians in Jackson County. Among his many awards were the American Legion Award in 1939 honoring his professional and community usefulness and the 1953 Award of Merit from the Jackson County Medical Society. He was a Diplomate of the American Board of Neurological Surgery, a Fellow of the American College of Surgeons, and a member of Nu Sigma Nu and Alpha Omega Alpha medical fraternities.

All of these things Doctor Teachenor had accomplished under many difficulties and adverse circumstances. His personal life was one that was beset with tragedy and suffering. For a number of years he was the victim of one serious illness after another, but at no time would he consider leaving his work permanently, and as soon as his health permitted he would return to his patients, surgery and teaching. His often expressed wish was that he would never live beyond his work, and we are grateful that this was so for him. He was also a lonely man as he had been preceded in death

by his immediate family, his wife, Ethel Heath Teachenor, and his son, Richard Heath Teachenor. His own losses, instead of turning him to bitterness and self-pity, seemed only to increase his depth of compassion for those who sought his help.

Some of us were privileged to have worked with Frank Teachenor, some of us were privileged to have known him as a personal friend, and all of us are privileged to have had him as a member of the medical profession. Through the years that lie ahead, there will be numbers of unfortunate individuals handicapped by illness and disease whose lives will always be a little more privileged because this man's life was given in the fullness of its time to his fellow men.

This is enduring greatness.

DONALD F. COBURN, M.D.

CORRESPONDENCE

FAMILIAL HEMANGIOBLASTOMA OF CEREBELLUM

To the Editor: It has been brought to my attention by Dr. F. Kieth Bradford that his Case No. 1 (M.L.M.) in "Hemangioblastoma of the posterior fossa (Lindau's disease). Report of two cases with familial history" (*J. Neurosurg.*, 1948, *5:* 196–201) and my Case No. 2 in "Familial hemangioblastoma of the cerebellum. Pedigree of two families" (*J. Neurosurg.*, 1953, *10:* 421–423) are members of the same family.

We wish to make this known so that an "extra" family does not appear in the literature dealing with this subject.

JOHN E. ADAMS, M.D.

University of California Hospital
San Francisco 22, California

NOTICES

THREE-YEAR RESIDENCY IN NEUROLOGICAL SURGERY

The Army Medical Service residency program in neurological surgery has been approved by the American Board of Neurological Surgery for three years at Walter Reed Army Hospital, Washington, D. C., beginning July 1, 1954.

Under the neurosurgical residency program, the residents will be so timed in their training that one new resident will be accepted each year and one will complete his training. The program actually will cover a four-year period since, in addition to the three years spent in formal clinical neurosurgical training, six months will be spent in clinical neurology and six months at the Armed Forces Institute of Pathology in neuroanatomy, neuropathology, and neurophysiology. The residents will have ample opportunity to pursue a course of laboratory investigation at the Army Medical Service Graduate School on a pertinent neurologic problem and also gain experience as instructors in teaching medical students from local universities, interns, graduate nurses, and junior residents.

AMERICAN ACADEMY OF NEUROLOGICAL SURGERY

At the meeting of the American Academy of Neurological Surgery held in Santa Barbara, October 12–14, 1953, the following officers were elected: President, Dr. Rupert B. Raney; Vice-President, Dr. David L. Reeves; Secretary and Treasurer, Dr. Eben Alexander, Jr. Members of the Executive Committee are: Doctors Rupert B. Raney, J. Lawrence Pool, David L. Reeves, George L. Maltby and Eben Alexander, Jr.

AMERICAN NEUROLOGICAL ASSOCIATION

The 79th annual meeting of the American Neurological Association will be held at the Hotel Claridge, Atlantic City, New Jersey from June 14–16, 1954.

CONGRÈS DES NEURO-CHIRURGIENS

The 5th Congrès des Neuro-Chirurgiens de Langue Française will be held in Algiers from April 19–21, 1954 under the Presidency of Professor P. Goinard. Subjects to be presented are "L'anesthésie en neuro-chirurgie" by E. Woringer (Colmar) and "Les indications respectives des diverses méthodes d'exploration radiologique en neuro-chirurgie" by M. David (Paris). American neurosurgeons are in-

vited to attend. Inquiries may be addressed to: Congrès de neuro-chirurgie de langue Française, 9 Avenue Claude-Debussy, Alger.

CONGRESSO NAZIONALE DI PSICHIATRIA

The 26th National Congress of the Italian Society of Psychiatry will be held at the Neuro-Psychiatric Hospital, Varese, May 6–9, 1954.

Reports will be given on (1) recent discoveries in infantile encephalopathy, and (2) new perspectives in quantitative differentiation between psychasthenia and schizophrenia. Participation of foreign colleagues is desired. The program will include excursions and other entertainment. The fee is 3,000 lire ($5.00). Address correspondence to: President of 26th National Congress of the Italian Society of Psychiatry, Neuro-Psychiatric Hospital, Varese, Italy.

NATIONAL INSTITUTE OF MENTAL HEALTH

The National Institute of Mental Health now awards research fellowships to postdoctorate investigators. The program is designed to assist young scientists and physicians in obtaining training and experience in research techniques and methodology which may be applied to the problems of mental health and illness. These fellowships are available to qualified research workers in many fields of science and medicine, such as biochemistry, neurophysiology, psychiatry, psychology, and sociology.

More detailed information is given in a new edition of the pamphlet entitled *Training and research opportunities under the National Mental Health Act*, single copies of which may be obtained free of charge from the National Institute of Mental Health, Bethesda 14, Maryland.

PAN-PACIFIC SURGICAL ASSOCIATION

Doctors are cordially invited to attend the 6th Congress of the Pan-Pacific Surgical Association to be held in Honolulu, October 7–8, 1954. Over 100 leading surgeons are contributing to the scientific program, which includes sessions in all divisions of surgery and related fields. An extensive social program is being developed for the doctors' families.

All hotel and travel reservations should be made through the Honolulu headquarters of the Association. Further information may be obtained from Dr. F. J. Pinkerton, Suite Seven, Young Building, Honolulu, Hawaii.

SCANDINAVIAN NEUROSURGICAL SOCIETY

The 10th meeting of the Scandinavian Neurosurgical Society will take place in Gothenburg, Sweden, September 3–4, 1954. Members of American and European neurosurgical societies are cordially invited to attend. Information is obtainable from the Secretary, Dr. Olaf Sjöqvist, Södersjukhuset, Stockholm, Sweden or from Dr. Gösta Norlén, Sahlgrenska sjukhuset, Gothenburg, Sweden.

SYMPOSIUM NEURORADIOLOGICUM

The 4th Symposium Neuroradiologicum will be held in London under the Presidency of Dr. James Bull, from September 13–17, 1955. Radiologists, neurosurgeons, neurologists and others interested will be most welcome. All wishing to contribute papers are invited to communicate as soon as possible with the Honorary Secretary, Dr. R. D. Hoare, at the National Hospital, Queen Square, London, W.C.1, England.

FORM-FITTING PLASTIC CRANIOPLASTY

WILLIAM T. SPENCE*
Georgetown University School of Medicine, Washington, D.C.

(Received for publication July 29, 1953)

THE methods of cranioplasty must progress with the times, the same as all types of neurosurgery, and it is the purpose of this paper to show the advantages of repairing certain cranial defects with a form-fitting plastic implant. The author has used a highly refined methyl methacrylate resin since November, 1947. The first plates are still firmly in place. At least five have been entirely satisfactory for 6 years.

The objections to metal plates run from scientific to personal. The latter is exemplified by the patient who said, "I do not want a lightning rod in my head." There is almost a social stigma to having "a silver plate in the head," and this takes a more serious turn when the individual is refused employment because of such. The scientific objections are as follows: (1) Metal resists X-ray penetration, thus interfering with X-ray therapy, ventriculography, arteriography, and visualization of the position of silver hemostatic clips. (2) Metal transmits heat and cold too readily, often causing headache. (3) Metal is difficult to work and make a suitable fit, especially if it is to be water-tight. (4) Metal bends easily to trauma, causing deformity and/or brain compression. (5) Working sharp edges may cut the operator's finger and even rounded edges may perforate the patient's skin. (6) Highly purified metals such as tantalum are ten times more expensive than plastic. Tantalum costs $1.50 or more per square inch, plastic about 25¢ a square inch. (7) The metal-bone relationship is not as natural as plastic and bone. Certain plastics look like, feel like, and cut like bone. Plastic screws are better tolerated than metal.

A liquid plastic to seal the cranial replacement and make it water-tight is being investigated at the present time. This would provide another advantage of plastic over metal.

Objections to rolled plates *per se* are: (1) Cranioplasty with a metal or rolled plate does not take into account the third dimension of depth in closing the defect. This results in a dead space into which herniation of the brain may occur (Fig. 1). (2) A plate over a hole, instead of in it, results in a rim of disturbed circulation where the inner tables meet the pulsating resistance of the herniating brain, i.e. the neck of the hernial sac (Fig. 2).

That metal plates have not been entirely successful has been mentioned by others. Grantham and Landis[6] reported that headache was not relieved in 50 per cent of the patients after cranioplasty with metal plates. Tuffier and

* 1150 Connecticut Avenue, Washington 6, D. C.

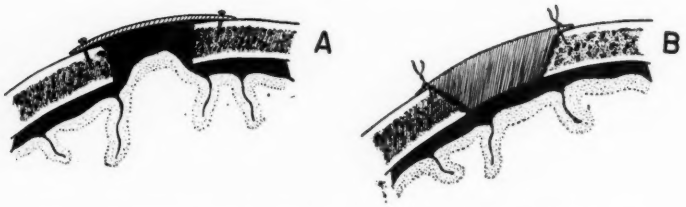


FIG. 1. (A) Herniation of brain into dead space beneath rolled type of plate. (B) Depth-fitting plastic cranioplasty.

Guillain[12] are cited as having found no improvement except a cosmetic one. Woodhall and Spurling[14] likewise found that generalized headache was unrelieved by tantalum cranioplasty.

The author's neurosurgical experience during 4½ years of World War II is contrary to the statement made by some that excellent shaping of metal for cranioplasty may be accomplished with ease.[13] The complexity of the procedure of metal cranioplasty is well borne out by Reeves'[10] monograph (pp. 1–42). For the most part, metal cranioplasty was a time-consuming process holding up the operating room for such long periods that it was abandoned as a primary procedure in combat. This was especially true when attempts were made to countersink the metal plates in a cutout of the skull around the edge of the defect such as has been recommended by others[1,3,4,10,13] working with metal or rolled plastic plates.

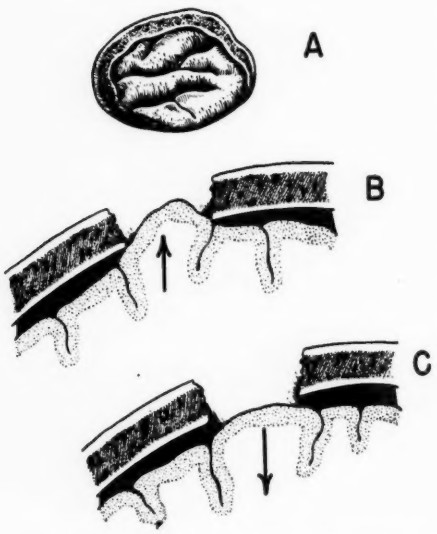


FIG. 2. (A) Skull defect showing circle of brain striking the skull edges. (B) Brain movement in systole, coughing, bending over, etc. (C) Brain falling back in diastole, dehydration, upright position, etc.

PRINCIPLES

Most everyone agrees now that cranioplasty is desirable. The reasons have been outlined by Grant and Norcross[5] and others. The author is in agreement with those who believe that the principal reason for improvement after cranioplasty is the better splinting of the brain. Gardner[4] emphasized this concept and his conclusions bear repeating:

"Since immobilization is important in wounds of baser tissues, it should be doubly important in the case of wounds of the brain. But when the surgeon closes the scalp over a brain

wound without repairing the cranial defect, he not only has not immobilized the structures, *he has allowed them to remain in a constant stage of pathologic mobility.*"

If this premise is fundamental in an improved physiology and if splinting of the brain is important, as it certainly seems to be, then *a better splint is equally important and desirable.* A purpose of this paper is to report a more physiological repair than has been possible with the covering type of plate, whether it be rolled metal or plastic.

Skull replacement by depth-fitting cranioplasty has resulted in not nearly as many complaints of headache, dizziness, apprehension, or abnormal sensations as have occurred previously when the covering type of plate was used. Immediate repair at time of operation or 10–14 days later during the same hospital period has been employed when practicable before the head is subjected to changes of position, jarring, coughing, and the normal amount of trauma absorbed by bus rides, bending over, straining, etc., in everyday activity. The underlying principle of inlay cranioplasty is to splint the brain in a normal position in its relation to the skull.

The principal objection to metal plates or other material that is cut in sheet form is that there is no accounting for depth. These materials are placed over the defect and not into it, so that there is a dead space between the plate and the dura mater. This is reduced but not eliminated when the plate is countersunk by the method described by Fulcher[3] and others.[9,10]

The method described in this report has been developed to eliminate as many disadvantages as possible, with the realization that any foreign body is not ideal. But finding it impossible to carve a suitable bone plate out of a good assortment of bone bank specimens, the method comes closer to replacing actual bone than any other. Shelden, *et al.*[11] used plastic (lucite) calvaria in monkeys as transparent windows for the study of the brain motion; however, these investigators did not advocate the use of lucite calvaria for skull replacement. Clark[2] subsequently used a lucite calvarium as a temporizing measure in a case of extensive avulsion of scalp, skull, dura mater and brain. Alexander and Dillard[1] used rolled plastic plates for skull replacement, but in the author's opinion such plates are mechanically unsound.

Tantalum has proven satisfactory in cranioplasty of areas where the skull is thin. It is of value when substituted for a bone flap in cases of tumors that necessitate re-operation or in cases in which a dead space beneath a plate is desirable to act as a decompression reservoir as described by Gardner.[4] Actually this can also be done easily with molded plastic since it is only necessary to place several thicknesses of cottonoid over the brain and mold the plastic over them. When the cottonoids are removed there is a dead space for the tumor to grow into, if such is desired.

METHODS

Plastic cranioplasty was first undertaken by the author in 1947 with the use of a highly refined methyl methacrylate resin. The first patients were treated by molding the plastic into the defect during the hardening proc-

ess.[7,8] The material comes in two forms, one a liquid monomer, and the other a powder polymer. The mixture is approximately two of powder to one of liquid by weight, and it was mixed in a metal dish with a spatula until the consistency was that of soft putty. At that point, it was molded in the fingers or gently pressed in the skull defect itself, in such a way that it was form-fitting both in depth and contour. There were several disadvantages to this method. The first was that the plastic powder was not sterile, but after mixing with the liquid polymer, cultures on six samples did not reveal any growth. Later on, positive cultures were grown from the powder, the liquid, and the formed plate itself. From these both aerobes and anaerobes have been isolated. The second disadvantage was that the heat of combination became so great that the plastic had to be taken up frequently during the hardening process, and it was difficult to arrive at a perfect fit. It was felt that the underlying brain could not be subjected to this amount of heat without damage.

For the above reasons it seemed desirable to make a cast of the defect. Several impression materials have been, and still are, being tried. Two methods were devised for an impression technique, which will be described in another report.

The rapid method, and the one that has been used almost exclusively for the past 2 years, employed a polyethylene bag to insure sterility and ease of handling. Otherwise, the soft plastic sticks to gloves. Now that the monomer and polymer can be sterilized (by strong ultra violet) the polyethylene bag technique is retained for ease of handling. Since the sterile material cannot be obtained everywhere, both techniques are described.

I. Using *Unsterile* Material. The cranial defect is prepared by cutting the skull edges with a slight bevel. The liquid monomer and powder polymer are mixed in the ratio of one to two at an unsterile table by the circulating nurse. The doughy mass thus formed is dropped into a polyethylene bag held open by the surgeon. This bag has been previously sterilized by a period of soaking in sterilizing solutions used in the daily routine of the operating room. The open end of the bag is clamped shut with any suitable clips available and the bag is placed on a flat surface where the soft plastic is rolled or formed into the desired size and shape. Usually this is into the shape of a round or oval patty, although it may be desirable to roll one part thicker than the rest, such as in forming orbital ridges.

The patty thus formed is placed over the cranial defect and light pressure is applied to gently countersink the patty into the area devoid of bone. Firm pressure is applied with the fingers, or the rolling pin, to the outer margins to create a flange over-ride around the edge of the defect that can be used to anchor the plate to the skull by one or two sutures or plastic screws (Fig. 1). The inlay thus formed is pressed gently in place for 2 or 3 minutes until the heat of combination is warm to the hand. At this time the plastic will hold its shape and it is lifted out of the wound by lifting up on the polyethylene bag that contains it. Complicated plates are best supervised by the surgeon during this late hardening stage since one must periodically keep the edges from curling or the contour from changing by bending it back into shape. Bubbles caused by the heat of combination can be broken by compressing

them with a sponge. Care must be taken not to burn one's fingers, and of course, a change of gloves is necessary after handling the unsterile plate. A simple plate, which does not necessitate such supervision, is handed back to the circulating nurse who takes the plate out of the bag.

All plates are placed 5 or 10 minutes in the high pressure autoclave. When sterilized the plate is passed back into the sterile field and any excess plastic is removed by rongeurs or a carborundum wheel attached to the electric bone drill. The latter does a good job of removing any stalactites or stalagmites that might have developed because of uneven pressure at the time of formation. The plastic replacement can also be polished by this means. It is conceivable that by careful approximation and a waterproof cement this type of cranioplasty could be made watertight. If temporal muscle and/or pericranium are available no other securing may be necessary. If no structures are present to stretch over the plate it can be held by one or two sutures of silk, wire, or plastic screws through bone and plate. The scalp is approximated in the usual manner. Fluid may or may not develop beneath the scalp and it is dealt with as in any craniotomy; usually it is no problem and drainage is not necessary. Mixing and fitting the plate takes about 5 to 10 minutes, hardening about 8 minutes and autoclaving about 5 minutes. Total time is about 20 to 25 minutes.

II. Using *Sterile* Material. The containers (ampules for the monomer and plastic envelopes for the polymer) are rendered sterile by the wet method or the material is merely poured from them into sterile receptacles on the instrument table.

After mixing the two ingredients the soft mass is placed between sheets of polyethylene and rolled, etc. as described above. The autoclaving step is unnecessary in this method.

The indications for the inlay plastic cranioplasty are the following: (1) The syndrome of the trephined. (2) Epilepsy resulting from injury causing the defect. (3) Protection of the brain from possible trauma. (4) Unsightly defects. (5) Painful and unduly pulsating defects. (6) Improvement of insulation of the brain. (7) Psychological factors, such as the elimination of anxiety and return of confidence. (8) The prevention of adhesions of the scalp to the dura mater and/or the brain. (9) Replacement of tumor-invaded skull flap by a substance that is sterile and will not slough or absorb.

My impression regarding the improvement in the epileptic after cranioplasty is the same as that of W. J. Gardner.[4] He proved that tantalum had no electronic action that exerted a neutralization effect on the cerebral focus. This view is supported by the fact that the same beneficial effect is accomplished by plastic cranioplasty.

Other advantages of plastic cranioplasty are: (1) The entire procedure can be carried out in a relatively short time compared to beating out complicated metal plates. It can be performed entirely at the time of operation and does not necessitate any elaborate equipment or assistance from the dental laboratory. (2) Plastic cranioplasty is form-fitting and may be made watertight. This procedure will be described in a later publication. (3) The cosmetic results are better than with metal. (4) The plate has nearly the same density and strength as bone. (5) The insulation is better than that of metal plates. Headaches from heat and cold are reduced. (6) The psychological ef-

fect is better than that produced by metal plates. The plastic is more similar to bone and a piece can be given to the patient for reassurance. (7) The depth of the skull defect is replaced to the level of the inner table, reducing dead space and effect of herniation. This splints the brain in a more natural manner. (8) Methyl methacrylate is not resistant to X-ray so that ventriculography or angiographic studies may be carried out without obstruction or distortion. The position of silver clips can be followed accurately in those cases in which there is a question of tumor recurrence. X-ray therapy is not interfered with. (9) Resin is approximately as resistant to EEG as is skull of the same thickness (Fig. 3). (10) Plastic cranioplasty will resist fracture and

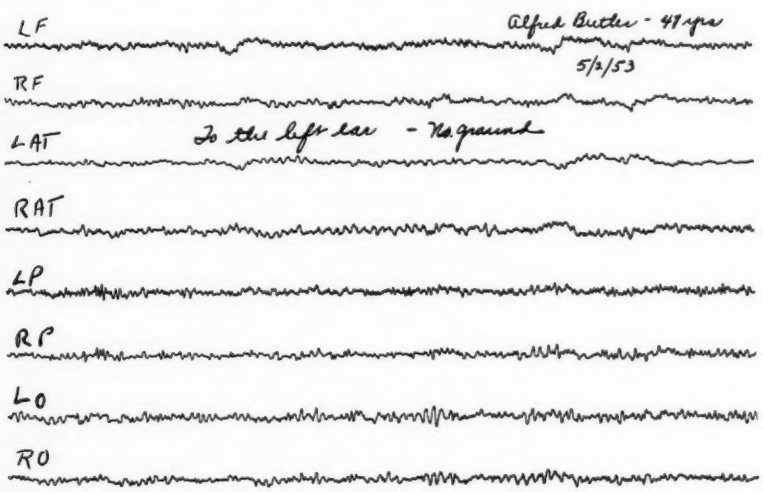


FIG. 3. Normal EEG over a plastic plate which replaces the patient's right parietal bone.

depression in nearly the same manner as bone. Also it will not maintain depression pressures as does indented metal. (11) The procedure of plastic cranioplasty is less expensive than that of tantalum. Methyl methacrylate is a less critical material. It is being improved and becoming less expensive constantly. (12) Fistulas may close spontaneously over exposed methyl methacrylate cranioplasties. A case of such a closure will be reported later. (13) Our preliminary studies show no indication that this substance is carcinogenic.

SUMMARY

1. An inlay type of cranioplasty is described that for the first time emphasizes the importance of depth in splinting the brain.

2. A method is presented in which a very highly refined methyl methacrylate resin* is used. It is a relatively simple, rapid and sterile procedure

* Cranioplastic kits are available from L. D. Caulk Company, Milford, Delaware.

and has proved satisfactory and safe in cases followed now since 1947.

3. Advantages of form-fitting cranioplasty over the covering type of plate are given, as are also the advantages of methyl methacrylate over metal.

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NOCARDIOSIS OF THE CENTRAL NERVOUS SYSTEM

ERICH G. KRUEGER, M.D., LUIGIA NORSA, M.D.,
MICHAEL KENNEY, M.D. AND PLINY A. PRICE, M.D.
Neurosurgical, Neurological, and Microbiological Sections,
Veterans Administration Hospital, Bronx, New York

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RECENT reviews of Nocardia infections in man[3,8,26] have devoted only scanty attention to the neurological aspects of this disease; yet in 56 cases of proven human nocardiosis collected to date, involvement of the central nervous system was demonstrable in 18 patients, and often appeared directly responsible for the fatal outcome.

The first pathogenic aerobic Actinomyces was isolated from cattle by Nocard[21] in 1888, and called Nocardia farcinica by Trevisan[25] in 1889. In 1890, Eppinger[10] isolated pathogenic aerobic Actinomyces from a brain abscess of a 52-year-old glassworker suffering from a pseudo-tuberculous infection and described the organism as Cladothrix asteroides. In 1896, Blanchard[5] renamed the organism Nocardia asteroides.

For many decades these organisms, which in their early stages of growth on culture media show structure similar to that of Actinomyces, were considered intimately related to the latter. Unlike Actinomyces, Nocardia is aerobic and primarily saprophytic, occurring on grasses, grains, and in the soil. In staining reactions it may or may not be acid-fast. Occasionally it gains access to the human body by airborne contamination or by introduction into previously traumatized tissues; and it may then disseminate widely by hematogenous routes. While rather sensitive to sulfonamides, it is relatively resistant to penicillin.

Pulmonary involvement in nocardiosis constitutes the most common clinical manifestation, thus, like actinomycosis proper, often simulating tuberculosis. While neurological complications are relatively rare in actinomycosis, involvement of the central nervous system, most often in the form of brain abscesses, has been reported in approximately 30 per cent of the cases of nocardiosis, thus rendering the prognosis of the latter more serious.

Since all known cases of nocardiosis of the central nervous system published to date, except 1 case of meningitis, were diagnosed either preterminally or post mortem, the following case report of a 42-year-old Negro, at present alive and well 15 months following excision of a Nocardia brain abscess, appears worthy of recording.

CASE REPORT

On April 22, 1952, C.K., a 42-year-old Negro laborer, was admitted to the Neurological Section of the Bronx V.A. Hospital with a 4-day history of right-side

hemiparesis beginning in the leg and extending to the upper extremity. There had been no headaches, convulsions, head trauma, unconsciousness, fever, or loss of weight.

The past history revealed an episode of right-sided pneumonia in 1938. Following the discovery of a positive blood serology in 1943, antiluetic treatment in the form of penicillin was given. During 1944, the patient was discharged from the Army with the diagnosis of bronchial asthma; and since that time daily chronic cough, productive of greyish-white sputum, had been present. For the past 10 years the patient had been a heavy cigarette smoker.

Examination. The patient was right-handed, well-developed, alert and cooperative. He did not appear acutely ill. The temperature was 98.6°F., pulse rate 80, and B.P. 114/80. There was diminished resonance with increased breath sounds over the right upper lobe posteriorly; wheezes and rhonchi were heard throughout the

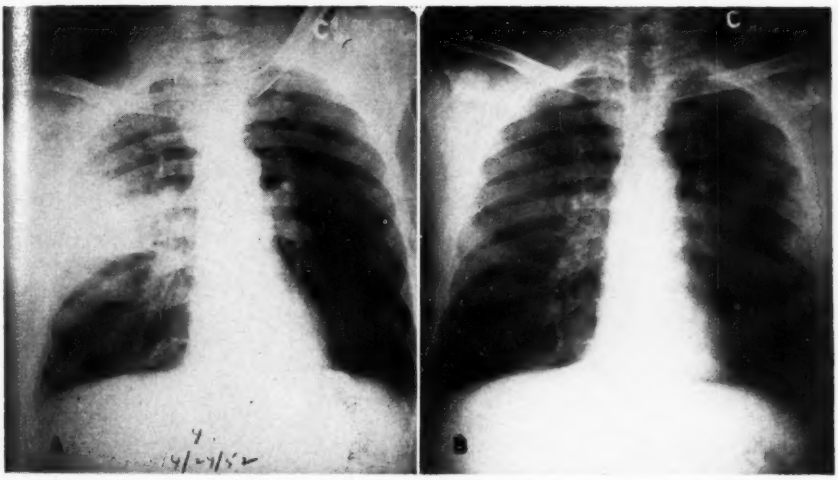

FIG. 1. (A) Admission chest film showing consolidation in right upper lobe. (B) Chest film of December 1952; note clearing of previous consolidated area of right lung.

chest. Positive neurological findings were marked weakness with areflexia of the right arm and leg, and an abnormal extensor plantar response on the right.

Routine laboratory tests and skull films were noncontributory. Roentgenograms of the chest showed consolidation of the subapical segment of the right upper lobe consistent with a diagnosis of bronchogenic carcinoma (Fig. 1A). A slow wave focus in the left motor area was present in the EEG.

Course. On the 2nd hospital day the patient had a series of right-sided Jacksonian seizures, following which a complete right hemiplegia developed, while the state of consciousness remained unchanged. Percutaneous left carotid arteriography on the 7th hospital day revealed mild depression of the left middle cerebral artery. A diagnosis of a metastatic bronchogenic carcinoma occupying the left motor cortex in the parasagittal area was made.

Operation. On May 1, 1952, under penicillin coverage and endotracheal anesthesia, a left frontoparietal craniotomy was performed. The exposed cortex re-

vealed flattening of the pre- and postcentral gyri. A round, firm, encapsulated mass was encountered parasagittally in the precentral gyrus approximately 1–1½ cm. below the surface. This mass was freed from the surrounding white matter on all sides down to a depth of 7 cm., and then removed *in toto* after some adhesions to the falx and superior sagittal sinus had been severed. During the process of removal, the capsule of the mass was broken into, and a small amount of greenish-yellow pus escaped. The operative field was irrigated with penicillin solution, and closure of the dura mater and of the remainder of the wound in layers was then carried out. The

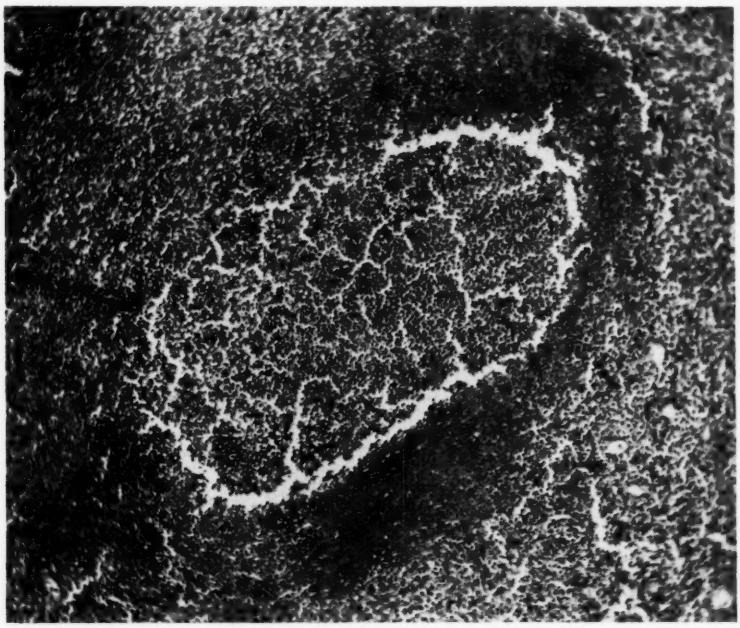

FIG. 2. Photomicrograph of surgical specimen showing focal abscess with leucocytic infiltration. Hematoxylin eosin stain, ×100.

patient withstood the procedure well; postoperatively he was placed on anticonvulsive, penicillin and aureomycin therapy.

Pathological Examination. The surgical specimen consisted of a 3.5×2.5×2 cm. rounded mass covered by greyish-yellow fibrinous exudate; on section of the mass, multiple, well-circumscribed, focal abscesses were noted. Microscopically these consisted of necrotic material and polymorphonuclear leucocytes, some of which extended into the surrounding tissue (Fig. 2). Rare colonies of basophilic branching filaments, without definite clubbing, were seen in the center of some of the abscess cavities (Fig. 3).

Bacteriological Report. Pus obtained at operation showed on smear a few gram-positive and gram-negative non-acid-fast rods; on culture it yielded a filamentous aerobic gram-positive, non-acid-fast fungus, later identified as belonging to the

genus Nocardia. The same organism was also cultured from a sputum specimen obtained on the12th postoperative day. *In vitro* tests proved it to be sensitive to aureomycin, chloromycetin, streptomycin, terramycin; and resistant to penicillin.

Since the Nocardia isolated from our patient apparently differed from any previously described species, a detailed description of its biological characteristics will be the subject of a separate publication.

Postoperative Course. The only complication was the transient accumulation of fluid under the scalp flap, which subsided following aspiration and the application of pressure dressings. By the end of the 1st postoperative week, the density in the chest film began to clear. Gradual recovery of function in the fingers, hip and knee

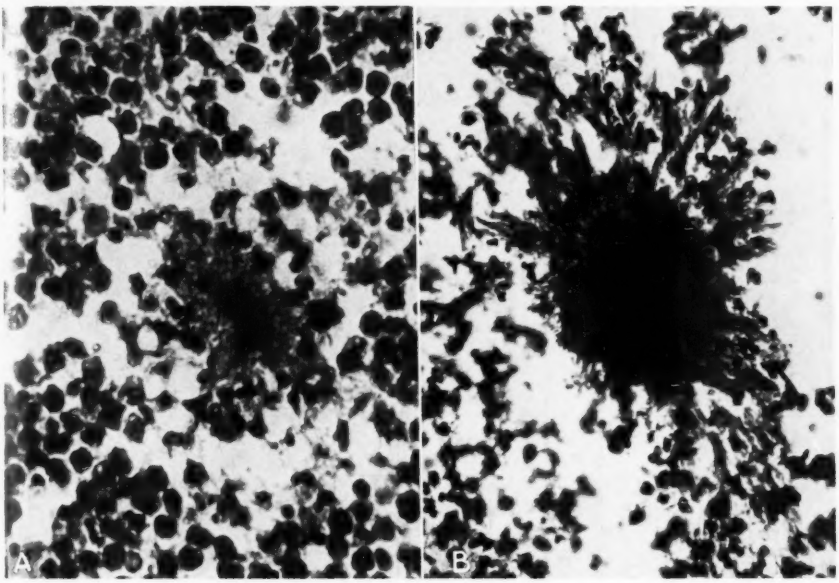

FIG. 3. (A) Photomicrograph of Nocardia in excised brain abscess. Hematoxylin eosin stain, ×600. (B) Another agglomeration of Nocardia in brain abscess. Hematoxylin eosin stain, ×600.

occurred during the 2nd week; and by the end of the 1st month the patient was able to ambulate with support. He received a total of 80 million units of penicillin and 75 grams of aureomycin over a period of 6 weeks; further antibiotic therapy was then discontinued in view of progressive clearing of the chest film.

By July 1952, free ambulation with the aid of a foot brace was possible. The x-rays of the chest at that time showed few linear fibrotic strands in the periphery of the right midlung, and remained unchanged thereafter (Fig. 1B). Examination of the spinal fluid in August 1952, revealed only a slight elevation in protein content of 57 mg. per cent. A sputum specimen obtained in December 1952, again yielded Nocardia on culture, although later cultures remained negative. Occasional right-sided Jacksonian seizures have occurred. The main neurological residual is a right-sided hemiparesis, most marked in the lower leg and foot, permitting ambulation and a fairly good use of the involved arm and hand.

TABLE 1

Verified cases of nocardiosis involving the central nervous system

Author	Sex Age	History	Neurological Signs	Course	Therapy	Autopsy	
						Central Nervous System	General
1. Eppinger,[10] 1890.	M 52	Lt. hemiplegia, 8 days. Meningitis, 5 days.	—	—	—	Subcortical lt. cerebral abscess communicating with ventricle. Meningitis.	Enlarged pulmonary nodes. Pseudotubercles in lungs & pleura.
2. Ferré & Faguet,[11] 1895.	—	Convulsions.	—	—	—	Lt. cerebral abscess.	—
3. Berestnew,[2] 1897.	—	—	—	—	—	Two brain abscesses.	Bronchopneumonia with cavitation.
4. Horst,[14] 1903.	M 33	Headaches, 3 wks.	Large lt. pupil, stupor.	Rt. facial palsy. Died 3rd hosp. day.	—	Multiple cerebellar abscesses.	Hilar abscess. Apical consolidation.
5. M'Donald,[20] 1904.	F 65	Giddiness, 3 yrs. Epigastric pain, 7 mos. Cough, 4 mos.	Paralysis rt. upper extremity, drowsiness.	Incontinence. Swallowing difficulty. Died 7th hosp. day.		Multiple abscesses (thalamus, internal capsule, lt. frontal, rt. parietal).	Pulmonary & renal abscesses.
6. Loehlein,[19] 1907.	M 58	—	—	Died 1st hosp. day.	—	Three temporal abscesses communicating with ventricle. Ependymitis.	Bronchiectasis.
7. Zeitlin & Lichtenstein,[27] 1937.	M 20	Cough, 1 mo. Anorexia, weight loss.	Stiff neck.	CSF: High pressure, 2240 WBC (chiefly polymorphonuclear). Chest film: Consolidation, lt. lower lobe. Died in 2 wks.	—	Rt. frontal abscess communicating with ventricle.	Lung abscess.
8. Kessel & Goolden,[17] 1938	—	—	—	—	—	Meningeal lesions.	Pulmonary lesions.
9. Binford & Lane,[4] 1945	M 51	Perirectal abscesses, 2 mos. Rt.-sided convulsions & weakness, aphasia, 9 days.	Rt. facial palsy, rt. hemiparesis, bilat. papilledema.	Died 10th hosp. day.	—	Multiple lt. cerebral abscesses.	Pulmonary & ischiorectal abscesses.
10. Kirby & McNaught,[18]	F 49	Headaches, nausea, vomiting, 1 mo.	Bilat. papilledema.	Ocular palsies. Died after lumbar puncture, 5th hosp. day.	—	Rt. cerebellar abcesssses.	Pulmonary nodule.
11. Jacobson & Cloward,[15] 1948.	F 28	Admitted for psychosis. Fever & headaches on 60th hosp. day.	Stiff neck, papilledema, bilat. abducens palsy, areflexia.	CSF: 4700 WBC (83% polymorphonuclear). Recovery; 5 mos. follow-up.	Sulfadiazine, penicillin (intrathecal), streptomycin (im, intrathecal). Ventricular	—	—

[illegible]	49	vomiting, 1 mo.		after lumbar puncture, 5th hosp. day.			
11. Jacobson & Cloward,[15] 1948.	F 28	Admitted for psychosis. Fever & headaches on 60th hosp. day.	Stiff neck, papilledema, bilat. abducens palsy, areflexia.	CSF: 4790 WBC (83% polymorphonuclear). Recovery; 5 mos. follow-up.	Sulfadiazine, penicillin (60 mg. intrathecally), streptomycin (1m, intrathecal). Ventricular drainage.	—	—
12. Tucker & Hirsch,[26] 1949, Case 1.	M 39	Infection of thigh, 7 mos. Headache, 3 mos. Focal seizures, rt. arm, 6 wks. Blurring of vision, aphasia, several days.	"Pointing to lt.-sided space-occupying lesion."	Died 4th hosp. day.	On 3rd day, lt. subtemporal craniotomy with drainage.	Lt. temporal & rt. frontal abscesses.	Subcutaneous abscesses.
13. Eckhardt & Pilcher,[9] 1950.	F 50	Headaches, 1½ yrs. Lt.-sided seizures, 5 wks.	Early bilat. papilledema.	Paresis lt. arm & face, 2nd hosp. day. CSF: high pressure, 8 lymphocytes, protein 89 mg.%. Died 4th hosp. day.	On 4th day ventriculogram & craniotomy with penicillin instillation.	Two rt. frontoparietal abscesses.	Apical scarring.
14. Bernstein, *et al.*,[3] 1952, Case 1.	M 39	Fever & subcutaneous abscesses, 3 mos.	Disorientation.	Mental deterioration. Chest film: Bilat. pulmonary infiltration. Died 4th hosp. wk.	Penicillin, streptomycin, aureomycin.	Multiple cerebral & cerebellar abscesses. Meningitis.	Pulmonary abscesses.
15. Bernstein, *et al.*,[3] 1952, Case 2.	M 60	Cough, 4 mos. Axillary mass, 2 wks. Stupor.	Lt.-sided hyperreflexia. Stiff neck.	Chest film: Rt. hydrothorax. CSF: protein 66 mg.%, high pressure, 910 WBC (60% polymorphonuclear). Died 4th hosp. day.	Sulfadiazine, penicillin, streptomycin, aureomycin.	Lt. occipital abscess communicating with ventricle	Chronic pulmonary reaction. Subpleural abscess.
16. Cruz & Clancy,[8] 1952.	F 43	Osteomyelitis of femur, 6 wks.	—	Orthopedic surgery to thigh. Died 5th hosp. wk.	Penicillin, gantrisin, terramycin for 2 days.	Small lt. occipital abscess.	Abscesses of heart, kidneys, adrenals, lymph nodes.
17. Kaufman & Prieto,[16] 1952.	M 53	Head trauma, 3 mos. Anorexia, 1 mo. Disorientation, drowsiness, 11 days.	Large lt. pupil, lt. facial palsy, stiff neck.	Chest film: Pulmonary consolidation. CSF: high pressure, no cells, positive Pandy. Died 5th hosp. day.	Negative bitemporal burr holes. On 5th day lt. parietal craniotomy with excision. Penicillin, streptomycin, for 1 day.	Multiple cerebral & cerebellar abscesses.	Bronchopneumonia. Abscesses of pancreas, & bronchopulmonary nodes.
18. Stevens,[24] 1950.	M 35	Abscess of buttock, 1 yr.; of chest wall, several mos. Convulsions, 1 mo.	Memory impairment, bilat. papilledema, bilat. Babinski.	Lt. hemiplegia. Increasing intracranial pressure, p.o. Died 4th hosp. mo.	Antibiotics. Craniotomy with excision lt. frontal abscess.	Multiple brain abscesses.	Subcutaneous abscesses.
19. Krueger, *et al.*, 1954.	M 42	Rt. hemiparesis, 4 days.	Rt. areflexia with extensor plantar.	Chest film: Consolidation rt. lung. Jacksonian seizures. rt. hemiplegia. Recovery.	Craniotomy with excision lt. frontal abscess. Penicillin, aureomycin for 6 wks. (15 mos. follow-up).		—

REVIEW OF THE LITERATURE

All known verified cases of nocardiosis of the central nervous system have been summarized in Table 1, which includes 18 patients with cerebral or cerebellar abscesses, and 1 with meningitis. In Pribytkow and Maloletkow's[22] case, which at autopsy showed meningitis and an intramedullary cord abscess extending from T2 to the conus medullaris, the diagnosis is suspected but bacteriological verification is lacking.

The patients range in age from 20 to 65 years, and males are affected more frequently than females. In general, neurological symptoms begin several months after the onset of extraneural manifestations such as cough or subcutaneous abscesses. Clinically, no distinct entity exists; neurological signs are related to localization within the central nervous system and to increased intracranial pressure. Pathologically, focal abscesses are much more common than primary meningitis. In almost all autopsied cases there have been additional visceral lesions, predominantly in the lungs and in the subcutaneous tissues.

Systemic nocardiosis, without involvement of the central nervous system, was invariably fatal up to 1944. Since then a few recoveries followed therapy with sulfonamides, either alone or in combination with penicillin,[6,7,12,13,23] and in one instance following the use of penicillin and streptomycin.[3] In cases in which there were neurological complications, the use of sulfonamide drugs and of antibiotics did not significantly alter the prognosis. However, the single patient with Nocardia meningitis on record recovered following massive doses of sulfadiazine, penicillin and streptomycin administered by intravenous, intramuscular and intrathecal routes.[15] On the other hand, antibiotic therapy in conjunction with craniotomy failed to avert the fatal outcome in 3 patients[9,16,24] who apparently showed neurological complications of greater severity and chronicity in comparison to our case.

The use of aureomycin following the removal of a cerebral abscess in our patient was instituted empirically because of the presence of a few gram-negative rods in one of the preparations of the pus obtained at operation. These gram-negative organisms were never recovered again and were considered to be contaminants. However, *in vitro* tests proved the Nocardia isolated from the abscess to be sensitive to aureomycin later on. The case observed by us constitutes the only reported instance of recovery from pulmonary nocardiosis complicated by a metastatic cerebral abscess.

SUMMARY

1. A case of pulmonary nocardiosis with development of a metastatic cerebral abscess has been reported. The patient underwent successful excision of a left frontal abscess and received penicillin and aureomycin in the postoperative course. Complete remission persists 15 and 13 months from the time of surgery and the time of discontinuance of antibiotic therapy, respectively.

2. The literature on nocardiosis and its neurological aspects has been re-

viewed. In a case of cerebral abscess, early surgical removal accompanied by intensive administration of sulfonamide drugs and of broad spectrum antibiotics appears to be the treatment of choice. Although a rare disease, nocardiosis should be considered in the differential diagnosis of metastatic brain abscesses or even tumors originating from primary pulmonary lesions.

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WATER EXCHANGE IN THE BRAIN AND CEREBROSPINAL FLUID

STUDIES ON THE INTRAVENTRICULAR INSTILLATION OF DEUTERIUM (HEAVY WATER)*

EDGAR A. BERING, JR., M.D.

Neurosurgical Research Laboratory and Neurosurgical Service of the Children's Medical Center, the Surgical Service of the Peter Bent Brigham Hospital and the Department of Surgery, Harvard Medical School, Boston, Massachusetts

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THIS paper describes studies that have been made on the cerebrospinal fluid (CSF) using deuterium oxide (D_2O, heavy water) as a water tracer to measure the water exchange from the cerebral ventricles into the blood. The disappearance of many other substances from the CSF has been studied by others.[8] These substances have always been used to identify CSF as a whole, and its movement, and many of the conclusions derived from these studies have been based on the premise of this identification. However, without more evidence that any one substance is representative of the CSF this is an invalid assumption, just as in the case of the blood plasma it would be invalid to assume that any one substance or ion represented all the constituents of the plasma. Until evidence is produced to show that the movement of the CSF is represented by any one substance, each should be considered separately and, therefore, in these experiments on water exchange it must be remembered that water alone is being measured and this is not necessarily a measure of any other component of CSF nor is it necessarily a measure of accumulation or absorption of CSF.

There have been several reports of specific pharmacological effects of D_2O on the central nervous system. In mice when D_2O replaced one-half of the body water sympatheticomimetic effects have been observed.[1,3] It is not certain that these were all caused by specific activity on the nervous system as there were also general metabolic disturbances. Herrmann[7] showed that in cats subdural injection of D_2O caused depression of activity and sometimes a cataleptic state which completely disappeared in 24 to 36 hours. During this period there was also a depression of electrical activity as measured by electroencephalograms (EEG). He also produced changes in the EEG with D_2O applied directly to the cortex. None of these effects was reproduceable by control experiments with normal saline solutions.

In primates similar catatonic effects were produced if D_2O was injected

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subdurally in amounts of 3.3 cc. per kg. body weight. All of the animals recovered and these effects could not be repeated in the same animal. D_2O caused no effect on sciatic conduction of frogs nor does aortic perfusion of D_2O affect the frog spinal reflex arc. Direct application of D_2O to the spinal cord of a cat had no effect on the knee jerk of a nerve-muscle preparation.

Stern and Dancey[12] reported studies on psychiatric patients after injection of D_2O into the lumbar subarachnoid space. They injected up to 20 cc. of 99.8 per cent D_2O as an isotonic saline solution and were unable to find any alteration of clinical state, neurological system, temperature, pulse, blood pressure, respiration, basal metabolic rate, sugar tolerance, blood cholesterol or kidney function. There was some CSF pleocytosis which lasted several days.

Most of the adverse pharmacological effects of D_2O reported in the literature occurred only when the dosage was 3 cc./kg. or greater. For the present study a dosage of 1 cc./kg. was adequate from the analytical point of view, but because the possibility of effects from high intraventricular concentrations remained the experiments were conducted with considerable caution.

MATERIALS AND METHODS

D_2O, 99.8 per cent pure, made into 0.8 per cent NaCl solution, was injected in amounts of 0.4 cc. to 2.4 cc. per kg. into the cerebral ventricles, or cisterna magna, and subsequently CSF samples were taken from the cerebral ventricles, cisterna magna and lumbar subarachnoid space and blood samples were taken from the superior longitudinal sinus or antecubital vein. D_2O analysis was carried out by densimetric[5] and mass spectrographic methods.[11] Monkeys (*Macaca mulatta*) were used for all animal experiments. All patients were from the Neurosurgical Service of the Children's Hospital.

A brief discussion of the interpretation of tracer dilution data is included for those unfamiliar with these techniques.

When a new substance or tracer is introduced into a volume of fluid by diluting it with a solution of uniform concentration the changes in concentration follow an exponential curve. Thus if equal volumes of two solutions are mixed, one containing the tracer and one not, the resulting concentration of tracer will be 50 per cent that of the tracer-containing solution. If this mixture is again diluted by one-half with the tracer-containing mixture, the concentration rises to 75 per cent, in the next step to $87\frac{1}{2}$ per cent, then to $93\frac{3}{4}$ per cent, etc., etc. If the tracer solution is being diluted this process goes in reverse: the concentration drops to 50 per cent, 25 per cent, $12\frac{1}{2}$ per cent, $6\frac{1}{4}$ per cent, etc., etc. with successive dilutions. In a continuously operating system of constant volume in which the tracer-containing solution is flowing into the non-tracer-containing solution the time required for the concentration to reach 50 per cent of the tracer-containing solution is known as the half-time as it indicates that one-half the original volume has been removed and replaced by an equal volume of tracer-containing solution. If the tracer is being diluted in a continuously operating system the time required for the tracer concentration to drop to one-half its original value is the half-time.

When this method of interpretation is used on biological systems the half-time serves as a crude measure of the tracer exchange rate. In the discussion of the results of the experiments reported in this paper the terms "ventricular exchange half-time," "appearance half-time" and "half-volume" will be frequently used. They are defined as follows: "ventricular exchange half-time" is the time required for one-half the D_2O to be removed from the cerebral ventricles after intraventricular injection; "appearance half-time" refers to the time required after intravenous injection of D_2O for the CSF D_2O concentration to reach one-half that of the blood-CSF equilibrium concentration; "half-volume" means half of the volume of CSF in the compartment considered. "Exchange" refers to the movement of D_2O out of or into the CSF and H_2O moving simultaneously in the opposite directions.

STUDIES ON THE NORMAL CEREBROSPINAL FLUID SYSTEM

D_2O was injected intracisternally in monkeys in amounts up to 1.9 cc./kg. without any adverse effect. The D_2O appeared quickly in the blood in high concentration and this rapidly fell to an equilibrium level. As these experiments did not seem to affect the monkeys in any way the studies were transferred to patients.

Intraventricular instillation of D_2O was carried out in 4 grossly retarded children with normal ventricular systems and CSF circulation. In the first patient an EEG was taken and then D_2O as 0.8 per cent NaCl was instilled into the ventricle in the amount of 0.43 cc./kg. The EEG was run intermittently for 3 hours without finding any abnormality. This was repeated in another child using a 1 cc./kg. dose of D_2O without any visible effect. In a third child a still higher dose of 2.4 cc./kg. was used and again no abnormalities were noted in the EEG or in the clinical status of the patient. Samples of blood taken from these patients 1, 2 and 3 hours after instillation showed D_2O levels consistent with complete mixture of the D_2O with the total body water. This is what would be expected from the studies of intravenously injected D_2O.[5]

In another patient 1 cc./kg. of body weight of D_2O saline solution was instilled into the cerebral ventricle and its appearance followed in the superior longitudinal sinus blood and the cisternal and lumbar CSF. The D_2O appeared very rapidly in the superior longitudinal sinus blood and soon achieved a stable level. It appeared quickly in the cisterna magna CSF; the concentration then fell, as did the ventricular concentration, almost reaching equilibrium with the patient's blood in 3 hours. Because of technical difficulties only two lumbar CSF samples were obtained. However, the second sample at 3 hours showed the same concentration of D_2O as the cisterna magna and the ventricles. These results are shown in Fig. 1.

The interpretation of these data must be approached with the utmost caution. The introduction of the D_2O in the amounts used causes such general disturbance of intraventricular conditions that it cannot be assumed that the measured results are representative of the normal conditions. The

amount of D_2O injected was probably equal to the volume of one ventricle so that the fluid already present must have been stirred up, and as the injection was made into the anterior horn, it is not at all unlikely that some of the injected material went into the third ventricle and through the aqueduct into the fourth ventricle and cisterna magna.

It is difficult to draw any conclusions about how or where the water gets from the ventricles into the blood. The first blood specimen was not taken until 16 minutes after the instillation and at this time the D_2O concentration in the blood was so nearly the equilibrium value that about 85 per cent of the D_2O must have been exchanged with H_2O from the blood. This means that the ventricular D_2O exchange half-time of this patient is in the neigh-

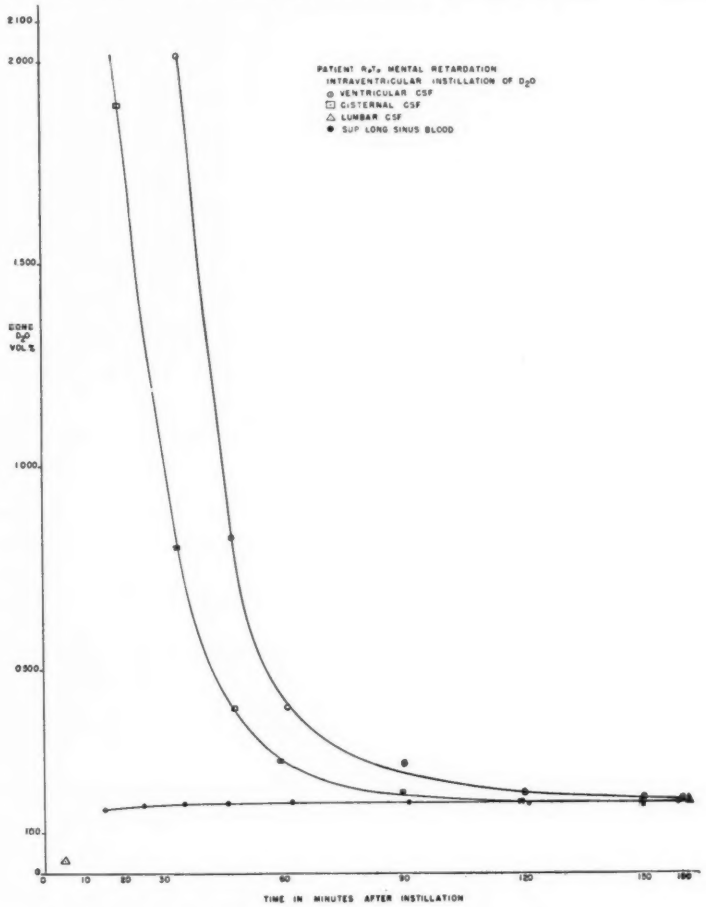

FIG. 1. R.T. Normal CSF circulation. Intraventricular instillation of D_2O.

borhood of 5 minutes* which is in good agreement with the normal ventricular D_2O appearance half-time of 2 to 11 minutes after intravenous injection of D_2O.[4] These data are summarized in Table 1.

TABLE 1

D_2O exchange after intraventricular instillation studies on patients with normal cerebrospinal fluid systems

Patient	Sex	Age (years)	Dose D_2O cc./kg.	Clinical Effects of D_2O	Ventricular Exchange Half-Time Based on TBW*
E. G.	M	7 3/12	0.43	None noted	†
J. B.	F	4 5/12	1.0	None noted	†
R. T.	M	8/12	1.1	None noted	About 5 minutes
S. R.	F	3/12	2.4	None noted	†

* Total body water.

† No blood samples taken early enough to make any reasonable estimates of the ventricular exchange half-time.

STUDIES ON PATIENTS WITH HYDROCEPHALUS

Three patients with hydrocephalus have been the subjects of four experiments. The 2 patients with non-communicating hydrocephalus each studied once with intraventricular D_2O, had been previously studied for D_2O appearance in the CSF following intravenous injection. One patient with communicating hydrocephalus was studied before and after arachnoid-ureterostomy.[9]

In 1 infant with an obstructed aqueduct of Sylvius, D_2O was instilled into one cerebral ventricle and the concentration changes in the CSF of both ventricles and the sagittal sinus blood were followed (Fig. 2). It required 2 hours for the tracer to reach equilibrium between the two ventricles. This suggests a lack of movement of CSF and very poor mixing characteristics of the ventricular system. The experiment was carried on for another 2 hours, and although the blood and CSF were not in equilibrium it could be calculated that 82 per cent of the D_2O had been absorbed. This calculation was based upon a total body water (TBW) determination previously made on this patient by intravenous injection of D_2O[6,10] and the assumption that the blood D_2O level represented the concentration of D_2O in the total body water. The D_2O ventricular exchange half-time estimated from the above calculations was found to be about 100 minutes which was in good agreement with ventricular D_2O appearance half-times of 90 and 120 minutes measured after intrave-

* This estimate is based upon two assumptions. (1) The blood D_2O concentration represents the total body water (TBW) D_2O concentration. (2) The TBW volume can be calculated from the blood D_2O concentration at equilibrium as described by others.[10] Since the concentration of tracer in the TBW and the total body water volume are known, it is a simple matter to calculate the amount of D_2O that has been removed from the CSF. This was found to be 85 per cent of the amount of D_2O injected into the ventricle. The principles of successive dilution as outlined in the methods section show that about 3 successive half-dilutions must have occurred to remove this fraction of the injected tracer. The time required for these 3 half-exchanges was 16 minutes, which means the half-time is about $5\frac{1}{3}$ minutes.

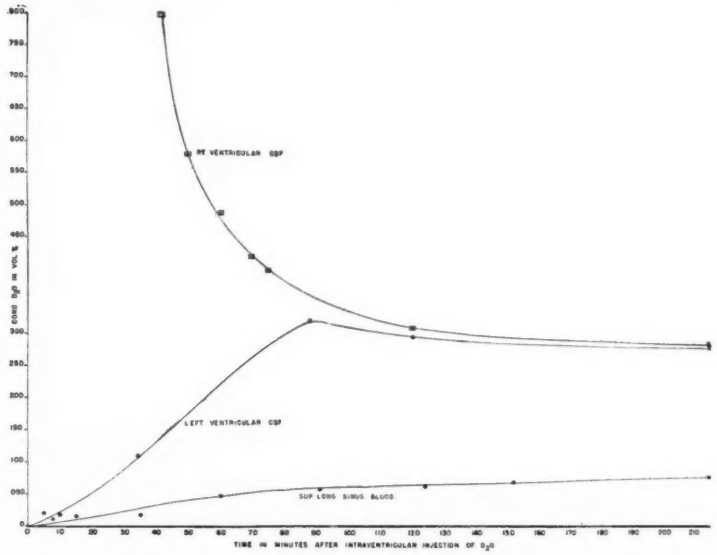

FIG. 2. K.C. Non-communicating hydrocephalus. D_2O injected into the right ventricle.

nous injection of D_2O. This same agreement between the D_2O exchange half-time of intraventricular and intravenous D_2O was found in the other infant with non-communicating hydrocephalus (Table 2). In the second infant the appearance of D_2O in the lumbar CSF was also studied. It did not appear in the lumbar CSF until after it had appeared in the blood. The lumbar D_2O concentration soon rose to equal that in the blood and then followed the

TABLE 2

D_2O exchange after intraventricular instillation. Studies on hydrocephalic patients

Pt.	Diagnosis	Sex	Age (years)	Ventricular Exchange Half-Time	
				Based on TBW after Intravenous D_2O	Appearance Half-Time after Intravenous D_2O
A. W.	Non-communicating hydrocephalus	M	3/12	180 min.	Over 180 min.
K. C.	Non-communicating hydrocephalus	F	3/12	100 min.	90–120 min.
S. K.	Communicating hydrocephalus	M	4/12	*90–100 min.	
S. K.	Communicating hydrocephalus after successful surgical treatment	M	5/12	80 min.	

* Some tracer lost on injection so that this calculation has an additional error in it which tends to increase the calculated exchange time.

blood curve but never exceeded it. This suggests that the lumbar D_2O was blood borne.

The results of the studies on the patient with communicating hydrocephalus are similar to those seen with obstructive hydrocephalus. The D_2O exchange is slower than in the normal patient but the CSF and blood do reach equilibrium in a few hours. The speed of exchange seemed to be dependent upon the size of ventricles rather than on the presence or absence of an obstruction in the aqueduct. In the preoperative studies (Fig. 3) the sudden

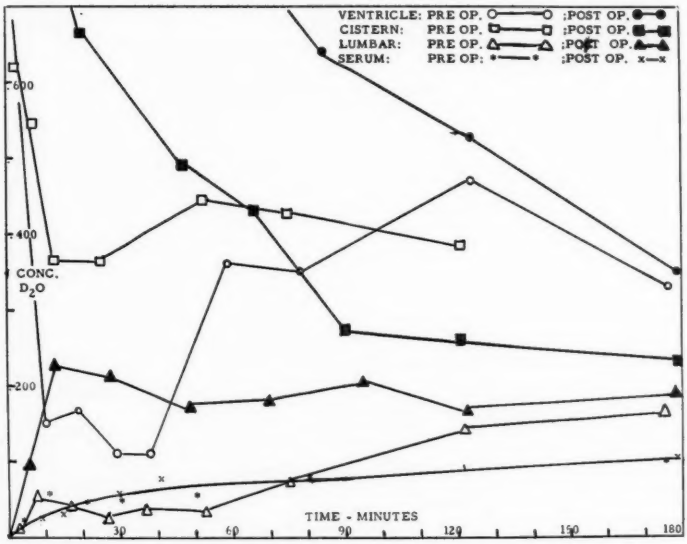

FIG. 3. S.K. Communicating hydrocephalus. Studies made before intraventricular instillation of D_2O, and after successful arachnoid-ureterostomy. The appearance of D_2O in the sagittal sinus blood was so nearly the same in both experiments that one line satisfied the data in both studies.

high concentration of the D_2O in the cisternal samples and the low ventricular concentrations suggest that the D_2O was injected almost directly at the foramen of Monro, allowing rapid passage into the cisterna magna. In the postoperative studies the ventricular and cisternal curves are quite different and are consistent with complete intraventricular instillation. However, the early rapid rise of the lumbar D_2O concentration without much increase later on suggests a current caused by the injection. The appearance of D_2O in the blood stream is equally rapid pre- and postoperatively, which shows that although the hydrocephalus has been brought under control with daily elimination of about 150 cc. of CSF via the bladder, there is no essential change in the molecular water exchange in this child. These studies are summarized in Fig. 3. The D_2O appearance in the blood is so nearly identical in

the pre- and postoperative studies that only one line has been drawn for both experiments.

In this latter patient no studies were done on the ventricular appearance of D_2O after intravenous injections of D_2O; however the estimated half-time in ventricular D_2O exchange of 80 to 100 minutes is in the same range as the D_2O appearance half-time found in similar patients.[4] The pre- and postoperative differences in the estimated ventricular half-time seen in this patient cannot be considered significant because some of the tracer was lost at the first injection causing an error that would tend to raise the exchange half-time.

There were 50 cc. of urine produced (patient was on catheter drainage) during the period of the experiment. It had a D_2O concentration which was well below both the early lumbar CSF and final blood levels. It probably came from the remaining kidney and reflects the low concentration of the blood with little or no contribution from the CSF.

After reaching equilibrium concentration, the D_2O disappeared simultaneously from the blood and CSF of all patients, normal and hydrocephalic.

DISCUSSION

The introduction of D_2O into the ventricles causes disruption of the physiological status of the CSF because of a suddenly added volume and because of the currents produced. These factors make these experiments almost valueless from the point of view of internal movement of CSF. However, in spite of these extraneous currents it can be said with considerable assurance that in the infant with non-communicating hydrocephalus the mixing characteristics were very poor. These same considerations of mixing qualities make this type of experiment involving intraventricular instillation of any ion or molecular tracer exceedingly difficult to interpret. Another important consideration is the blood samples. To ascertain how much tracer is being taken up at any one time, both arterial and sagittal sinus blood must be used. In these children consideration of size and blood volume limited the studies to venous samples alone.

Obstruction of the aqueduct of Sylvius does not prevent removal of D_2O from the ventricular CSF, and the D_2O exchange seems to proceed at the same rate whether given intravenously or placed in the ventricle. The passage of D_2O from the ventricular CSF to the blood stream is slower in the hydrocephalic patients than in the normal patients, but this is to be expected because in the hydrocephalic patient the exchange area-volume ratio is much smaller than in the normals. This principle has been covered in detail elsewhere in studies on the appearance of D_2O in the CSF.[4]

Subarachnoid-ureterostomy did not appear to affect the amount or rate at which the D_2O entered the blood. This suggests that the physiological range of CSF pressure changes does not affect molecular movement of water, and its movement is controlled by the laws of diffusion.

SUMMARY

1. Small amounts of D_2O can safely be put into the cerebral ventricles without causing abnormalities in the EEG or general clinical status of a patient.

2. In the normal state D_2O placed in the cerebral ventricles is in equilibrium with the total body water in about 3 hours.

3. The D_2O exchange half-times after intraventricular D_2O were in very good agreement with the D_2O appearance half-times after intravenous D_2O.

4. In obstructive hydrocephalus, the tracer appearing in the lumbar region is probably carried there by the blood after being absorbed from the ventricle.

5. In spite of the upset of physiological status following an intraventricular injection of saline, there seems to be very little gross movement of CSF in an infant with non-communicating hydrocephalus.

6. Studies on patients with non-communicating hydrocephalus and on patients with communicating hydrocephalus undergoing subarachnoid-ureterostomy show that the exchange of water is independent of the accumulation of CSF.

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TUBERCULOMAS OF THE BRAIN AND CEREBELLUM

P. DESCUNS, M.D.,* H. GARRÉ, M.D., AND C. PHÉLINE
Algiers, Algeria

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THE results of the surgical removal of tuberculomas of the brain and cerebellum have been transformed in recent years by the judicious use of Streptomycin associated with other antibiotics. Formerly tuberculous meningitis was a common occurrence in the postoperative period, and almost all patients with tuberculomas of the cerebellum and the majority of those with a tuberculoma of the brain succumbed. Nowadays, by observing certain precautions the postoperative results are greatly improved.

A few years ago, some of the foremost neurosurgeons still performed a mere decompression associated with medical therapy. Now, under the protection of antibiotics, it is possible to remove, even piecemeal, all of the intracranial tuberculomas that are surgically accessible.

This complete change in prognosis was particularly appreciated in North Africa, where the incidence of intracranial tuberculomas is very high, chiefly among young people, and especially among natives.

INCIDENCE

Only 3 of the patients were European; 35 were natives.

Fifteen patients were under 16 years of age, and of the 23 adults, the majority were between 20 and 30 years of age. Our oldest patient was aged 60 years.

There were 12 females and 24 males.

Most of the intracranial tuberculomas appeared as primary lesions and there were only few cases in which there was an associated tuberculosis in the lung or elsewhere. But those patients usually lived in a badly infested family.

PATHOLOGY

Sixteen (42.1 per cent) of the tuberculomas were located in the posterior fossa: 7 in the right hemisphere, 7 in the left, 1 in the vermis, and 1 in the brain stem.

Contrary to what has usually been held, location in the cerebral hemispheres was more frequent. There were 22 (57.9 per cent), situated as follows: 10 in the right hemisphere; 10 in the left; and, in 1 instance, in both frontal lobes.

The lobes most frequently affected were in order: (1) the parietal lobe, (2) the occipital, (3) the temporal, and (4) the frontal.

* 3 Rue Lafayette, Algiers, Algeria.

Gross Pathology. When the bone flap is lifted, one may find that the dura mater has an unusual appearance. It is often rough, with small foci of bone metaplasia. The dura mater is often adherent to the tuberculoma. In some cases, tuberculous granulations on the pia mater make the diagnosis clear. The convolutions are flattened, and sometimes there is marked edema of the brain. The brain is yellowish and has a jelly-like consistency, because a certain amount of tuberculous encephalitis *always exists* around the tuberculoma. This is more marked with cerebral tuberculomas than with those of the cerebellum.

Antibiotics have a strong effect on this encephalitis and thus prevent infection of the meninges. One can easily remove the tuberculoma from the surrounding area of encephalitis. Usually the tuberculoma has few blood vessels. However, in 2 cases of parasagittal tuberculomas that were highly vascular, the diagnosis of meningioma was suspected.

The shape of the tumor may vary (Fig. 1). It is generally round, and often "bun like." The size is usually greater than anticipated, especially in cases of tuberculoma of the posterior fossa. Most of those we operated on were bulky, their size varying between that of a walnut and a tangerine. A huge one weighed 210 grams; the smallest one was surrounded by an extensive area of tuberculous encephalitis. In one case a coating of multiple tuberculomas was found around the frontal lobe.

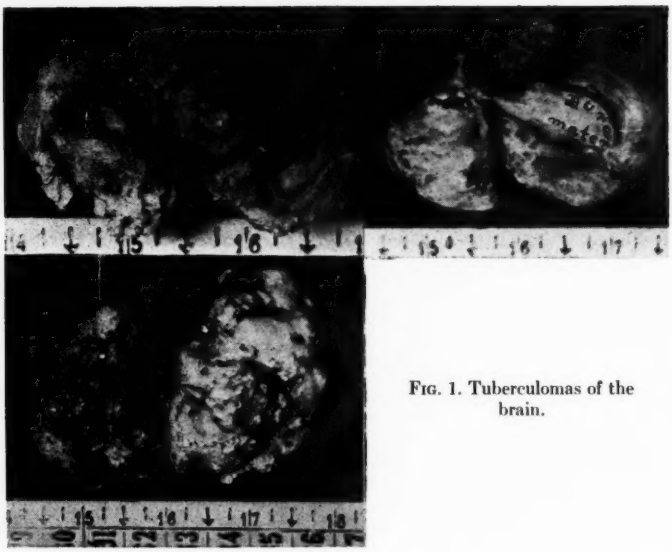

FIG. 1. Tuberculomas of the brain.

Some tuberculomas, though comparatively rarely, are not amenable to any form of surgical treatment. Classically, when sectioned, the tumor resembles a raw chestnut, although sometimes it has the appearance of a chronic tuberculous abscess because of calcification or caseification.

CLINICAL ASPECTS

Cerebral and cerebellar tuberculomas behave like all intracranial tumors and give differing signs, according to their location. However, some peculiar points may be noted: First is the importance of intracranial hypertension, which progresses very rapidly and often obscures all other signs. Many patients (50 per cent) came to the hospital when they were already blind, with secondary atrophy and signs of compression of the brain stem (nuchal rigidity, mydriasis on one side only).

Though the natives are strongly fatalistic, that is not the only reason for their deferring any consultation. Another factor is the rapid increase in intracranial pressure, *which is caused more by the tuberculous encephalitis than by the size of the tuberculoma.*

When located in the posterior fossa, the high intracranial pressure is conspicuous and the cerebellar symptomatology is very poor, and in such instances among young natives, we often suspect a tuberculoma.

When located in the brain, they may cause but few more symptoms. We noted some Jacksonian fits (in 4 of 22 cases) and even less often, generalized epilepsy. Frequently, lateral homonymous hemianopsia and hemiplegia were the only signs associated with high intracranial pressure.

Roentgenograms of the skull revealed the syndrome of intracranial hypertension: "finger prints," separation of the sutures, and erosion of the sella turcica. Calcification of a tuberculoma was rarely seen.

Examination of the fundi revealed papilledema, and, in 50 per cent of the cases, secondary atrophy of the optic nerve.

X-rays of the chest were systematically performed and, in a few cases only, showed pulmonary tuberculosis associated with the brain lesions.

Electroencephalographic Findings. Of 11 patients who had electroencephalography, 8 suffered from cerebral tuberculomas, and 3 from cerebellar tuberculomas. The basic rhythm was often slowed (7-9 c/sec. in the cerebral location of the pathological process). Diffuse fast activity was recorded in 4 cases: 2 tuberculomas of the left cerebellar hemisphere, 1 tuberculoma which damaged both frontal lobes, 1 which was deeply located in a cerebral hemisphere. This fast activity in cases of tumors of the posterior fossa and lower brain stem and, lately, of tumors of the cerebral hemispheres, has been previously described by others.

It seems of interest to emphasize the great number of spiky abnormalities with this kind of tumor (recorded in 6 out of our 8 cerebral cases). These abnormalities consist of sporadic or continuous fast spikes, sharps, spike and waves which were closely localized to the area of tumor or lateralized to the injured side; they might also appear as random discharges of rhythmic sharps or spikes, in the opposite side, or diffuse. One of our patients showed paroxysmal activity of rhythmic temporal spikes which resolved clinically in a psychomotor fit.

These changes might be the only sign of the tuberculoma or be associated with localized slow activity (delta-téta waves); one must observe that this

spike activity agreed partially with clinical data, since these tracings were found among the 3 epileptic patients we were able to record.

Ventricular puncture may be sufficient when a tuberculoma of the posterior fossa is involved. It reveals the hydrocephalus with hypertension which corroborates the diagnosis of the location. When a tuberculoma of the cerebrum is concerned, it can be met by the ventricular needle.

Ventriculography (Fig. 2) is not free from dangers. It can increase the cerebral edema which is always important because of the tuberculous encephalitis and may cause serious accidents, such as squeezing of the brain stem. The tuberculomas of the posterior fossa give a threefold ventricular expansion which can vary in importance. The X-ray appearance of the tuberculomas of the brain is much the same as that of brain tumors: dislocation or

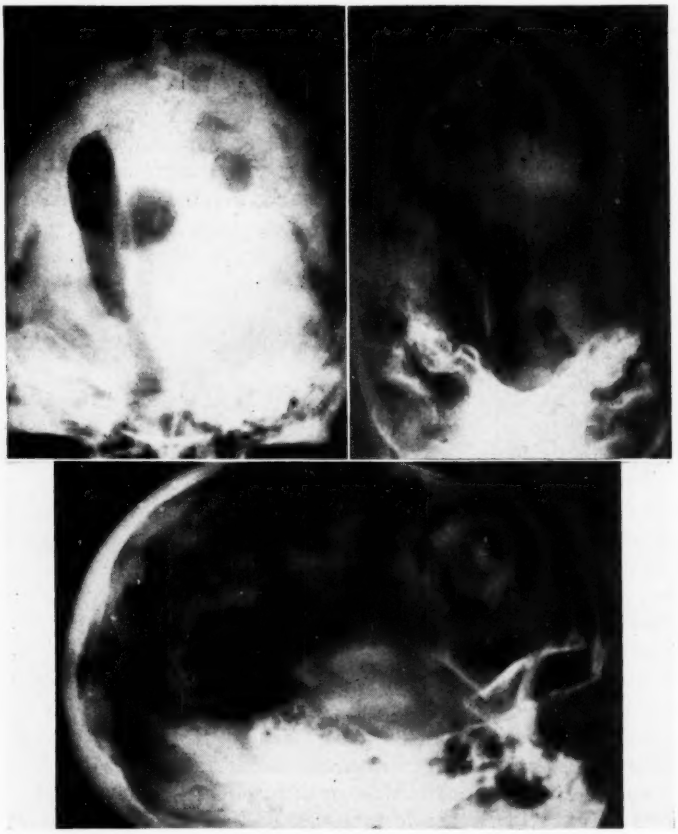

FIG. 2. Ventriculograms in cases of tuberculoma. Note signs of intracranial hypertension and squeezing of the temporal lobe.

indentation of the ventricular system; a shift in the ventricles denotes frequently a temporal lobe squeezing.

Angiography (Fig. 3) is the preferred means of localization of a tuberculoma of the hemisphere. The vessels are pushed aside by the tumor and disappear in its locality.

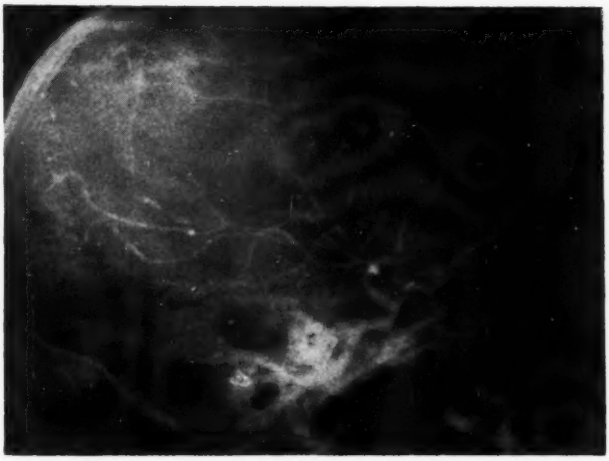

FIG. 3. Angiogram in a case of tuberculoma of the right parietal lobe.

TREATMENT

Until these last years, brain surgeons had the constant fear of tuberculous meningitis when they tried to remove a tuberculoma, especially when the lesion was in the cerebellum. Indeed, infection of the spinal fluid occurred when piecemeal removal of the tuberculoma had to be made (particularly in the posterior fossa). But tuberculous encephalitis also aggravated the condition. Though the spinal fluid often was under shelter because of the adherence of the cortex to the meninges, this was too frail and small a defense to allow a dry operation. Tuberculosis of the meninges occurred in the postoperative course in most cases of tuberculoma of the brain, and always after removal of a tuberculoma of the cerebellum. Therefore it became Cushing's custom when a cerebellar tuberculoma was surgically disclosed to leave the operation as a decompression and to prescribe heliotherapy.

Today, through the use of Streptomycin, the problem is quite different and when the diagnosis has been established, treatment must be instituted as soon as possible. The method of extirpation varies according to whether the tuberculoma is in the brain or cerebellum.

Tuberculomas of the Brain Hemispheres. Once we know by angiography the exact location of the tuberculoma, the flap is cut where needed. Usually the dura mater is very tight because of an underlying cerebral edema; when it is opened, the brain protrudes, and one can see the convolutions, flattened

just as they are over a cerebral tumor. In some cases, small granulations, typical of tuberculosis, have formed, especially along the vessels.

A tuberculoma may reach the level of the cortex, and in that case the dura mater and cortex are adherent. If not, brain puncture with Cushing's needle locates the lesion and an approximate estimation of its size may be made. A cortical incision identifies the nature of the tumor. A cap of the cortex that covers the encephalitic zone is resected. It is not absolutely necessary to remove all of this parenchyma, especially when it is close to a highly functional area.

The tuberculoma is easily extirpated. It usually has few vessels and these are coagulated as the surgical removal proceeds. The ventricle should not be opened if possible. The cerebral edema gradually disappears and the brain slackens after a careful check of bleeding. Streptomycin powder (1 gm.) is left in the cavity. The wound is then closed as usual in brain surgery.

When the tuberculomas are located in the frontal, occipital or right temporal lobes, a typical lobectomy can be performed with removal of the tuberculoma and the surrounding zone of encephalitis.

Tuberculomas of the Cerebellum. We use a "cross-bow"-like incision on one side only; then make a permanent resection of the occipital, which gives a wide exposure of the posterior fossa.

When no exact location has been determined, we begin by a midline incision and open sideways as needed. We almost always have to perform a ventricular puncture. The meninges are then opened, the posterior occipital vein is ligatured and the cerebellum is freed by opening the cisterna magna.

As soon as we suspect a tuberculoma, we protect the cisterna magna *constantly by a piece of cotton moistened with Streptomycin*, so that the operation is done under a continuous flow of antibiotic.

The tuberculoma sometimes reaches the cortex, but more often we have to puncture to locate it. A flap of cerebellar cortex is then lifted up so that the lesion is best exposed.

But, unless it is a very small one, it is very difficult to remove it whole. Its size is often huge, so that we have to proceed by piecemeal extirpation, first emptying the tuberculoma. This is not without danger because of the brain stem which is often displaced and crushed, and, in the postoperative course, the patient often has to be left in the same position for several days. After a careful check of the bleeding, Streptomycin (1 gm.) is left *in situ*. Most of the tuberculomas can be totally removed.

PRE- AND POSTOPERATIVE COMPLICATIONS

We seldom met with complications in cases of tuberculomas of the brain, although in a few instances severe postoperative edema occurred and one of our patients succumbed. The latter had a medium-sized tuberculoma with an extensive zone of encephalitis. Before the operation, a high degree of edema of the brain had been successfuly treated; 3 days later under a second acute surge, the patient died in spite of our endeavour. At autopsy a squeezing of the temporal lobe was found.

TABLE 1

Results of surgical treatment of intracranial tuberculomas

	No. of Cases	No. Healed	Died
Before use of Streptomycin	10	2	8*
Since use of Streptomycin	28	15†	13
Total	38	17	21
According to location			
Brain	22	11	11
Cerebellum	14	6	8
Brain stem	1		1
Vermis	1		1
Total	38	17	21

* All 8 patients had tuberculous meiningitis.
† One patient is still being treated.

As far as tuberculomas of the cerebellum are concerned the accidents come from the shifting of the brain stem after the tumor is extirpated. In one of our cases marked cerebral edema occurred, such as was described by Clovis Vincent as an exceptional and fatal accident. The patient was a woman with a very large tuberculoma of the right hemisphere that had to be freed from the fourth ventricle, and the edema occurred at that time. Leaving part of the tumor, we closed the wound as quickly as possible. The patient lived, and 15 days later in a second operation we were able to remove the rest of the tumor. This patient did not have any Streptomycin until later, and that did not stop a tuberculous meningitis from appearing 20 days after the first operation. She died 2 months later.

This brings us to the problem of the postoperative treatment. On the same day when the removal is done, the patients are treated with large doses of Streptomycin, as well as with vitamins, calcium and so on.

On the next day, we give two injections of Streptomycin by lumbar puncture. The fluid is checked regularly, so that the least accident is noted; this treatment is continued daily for about 1 month. Successful healing can be expected only at such a cost.

If the ventricle happens to be opened, ventricular puncture is necessary for a few days, leaving 0.05 gm. of Streptomycin.

PARTICULAR CASES

Some locations are not surgically accessible, and in such cases only palliative operations are performed, such as third ventriculostomy for a tuberculoma of the brain stem (protuberance for instance), or the Torkildsen procedure when the tumor is in the thalamus, the pineal body, and even extends to the third ventricle, so that a third ventriculostomy would not be effective.

After these palliative operations we have seen many patients live much longer than expected and even heal completely when Streptomycin acted well.

RESULTS

One has to remember that most of our patients were admitted to the hospital with a marked increase in intracranial pressure; 50 per cent were blind when operated upon, which accounts for the high mortality (Table 1).

In a single case of posterior fossa tuberculoma the patient died of meningitis. The other patients had huge tumors, and some of them were nearly beyond the hope of any surgical treatment.

CONCLUSIONS

The prognosis of tuberculomas of the brain and cerebellum has been greatly improved since the use of antibiotics during and after operation.

These tumors hitherto caused many deaths. They can be healed now but especially in North Africa, one realizes that an earlier diagnosis would allow operation on moderate-size tuberculomas in contrast to the huge neoformations that are seen in these blind patients we usually operate upon.

Finally, three points should be emphasized in the treatment of tuberculomas of the brain and cerebellum: (i) When the meninges are opened above a tuberculoma of the cerebellum a continuous flow of Streptomycin is needed. (ii) Streptomycin (1 gm.), must be poured into the bed of the tumor. (iii) Early in the postoperative course, treatment with Streptomycin, vitamins, calcium and so on is necessary by general and local measures.

GLIOBLASTOMA MULTIFORME OF SEPTUM PELLUCIDUM

JOSEPH G. CHUSID, M.D., AND C. G. DE GUTIÉRREZ-MAHONEY, M.D.
Neurological Division, St. Vincent's Hospital, New York, New York

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TUMORS of the septum pellucidum occur infrequently and clinically are rarely recognized. In their extensive review, French and Bucy[4] presented 5 cases and collected 31 more cases from published descriptions. The present case report together with 20 additional cases cited from the literature raises the total of confirmed cases of tumor of the septum pellucidum to 57.

REPORT OF A CASE

History. A 72-year-old woman was admitted to the Medical Division at St. Vincent's Hospital on Dec. 26, 1952 with a history of diarrhea and vomiting of a month's duration. The history was difficult to obtain because of severe bilateral deafness and associated abnormality of speech since early childhood, to which was added a language barrier. She had recently come under the care of her referring physician who advised hospitalization primarily for the purpose of gastrointestinal study.

Examination. Except for a severe grade of bilateral deafness, no significant abnormalities were noted. She was described as being cheerful, alert and uncomplaining.

Course in Hospital. An electrocardiogram made on Dec. 27, 1952 was interpreted as showing changes compatible with a recent posterior wall infarct. Complete blood count, urinalysis, blood urea nitrogen, fasting blood sugar and blood serology were unremarkable.

She vomited repeatedly on December 28 and 29. During the afternoon of December 29 she was found sitting on the floor without apparent cause. On the next day it was reported that she apparently had fallen out of bed. Lumbar puncture on December 30 disclosed "turbid" CSF under an initial pressure of 100 mm. water, with 7 mononuclears per c.mm., negative Kahn and total protein of 510 mg. per cent.

On Jan. 3, 1953, she vomited several times. About midnight, a scream was heard issuing from her room and she was found sprawled under the bed of a neighboring patient. She complained thereafter of pain in the right hip and head. A gastrointestinal x-ray series made on Jan. 5, 1953 disclosed a hiatal hernia. Repeat lumbar puncture on Jan. 7, 1953 was performed with difficulty and blood-tinged CSF under normal pressure was obtained. Vomiting continued frequently thereafter and she was then described as being tremulous and somewhat lethargic.

On Jan. 15, 1953 she was seen in consultation by a neurologist. She appeared bright, alert but uncooperative. She scowled as she moved about in bed; sometimes she mimicked the examiner. B.P. was 170/106 in right arm in supine position. Deep reflexes were moderately and equally exaggerated and both plantar responses were extensor. The extremities could be moved freely; there was a moderate grade of cogwheel rigidity of the musculature of all extremities. No evidence of papilledema was

detected. She made no vocal sounds during the examination. Skull x-rays were normal.

On Jan. 16, 1953 EEG showed a moderate grade of diffuse slowing, most prominent in the anterior halves of both cerebral hemispheres. Lumbar puncture revealed clear CSF under an initial pressure of 110 mm. water, with 4 mononuclears per c. mm. and 480 mg. per cent total protein. Permission for ventriculography was denied.

The next evening her temperature rose to 102°, breathing was rapid and shallow; she became semicomatose, responding only occasionally to painful stimulatio . Thereafter, she remained dyspneic, cyanotic and comatose and expired on Jan. 20, 1953.

Necropsy. The external appearance of the brain was unremarkable. When the brain was sectioned following fixation in formalin, a tumor of the septum pellucidum measuring 2.7×3.0×2.3 cm. was disclosed (Figs, 1, 2, 3). The tumor projected into the left lateral ventricle and to a much lesser degree into the right. Moderate symmetrical dilatation of the lateral ventricles was evident. Both interventricular foramina appeared compromised, with the left being smaller than the right. The surfaces of the sectioned tumor appeared speckled with small pinhead-sized reddish areas interspersed with much larger gray and yellow patches; a dark red zone approximately 6 mm. in diameter was centrally situated. The tumor extended into the inferior rim of the anterior corpus callosum for approximately 2 mm. and into the region of the left anterior basal ganglia about 5 mm. X-rays of coronal sections of brain (including tumor) did not reveal any evidence of calcification. Additional

FIG. 1. Coronal section showing anterior limits of tumor of septum pellucidum.

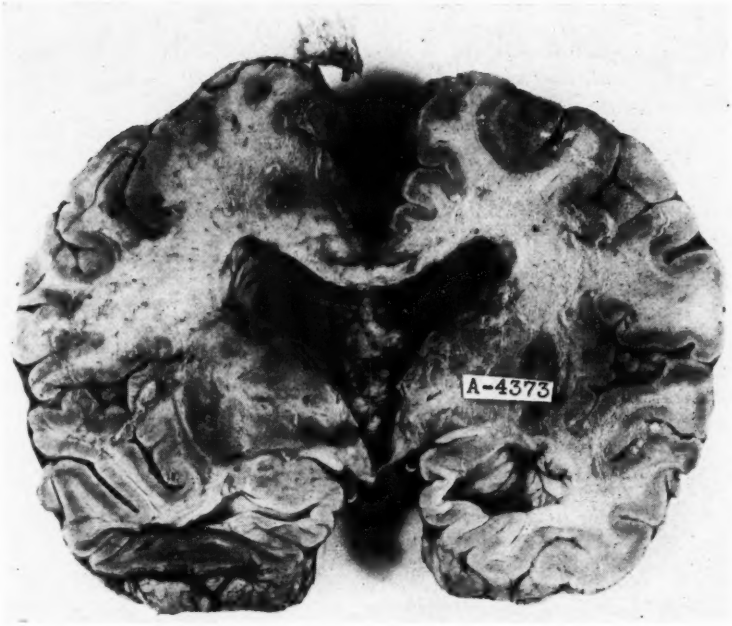

FIG. 2. Coronal section showing posterior aspect of tumor of septum pellucidum.

findings included: diverticulosis and diverticulitis of the rectosigmoid junction, benign nephrosclerosis, and emphysema.

Microscopic Examination of Tumor. The major portion of the tumor was very cellular. Elongated nuclei arranged in more or less parallel streams were prominent. These nuclei contained fine granular chromatin material and were rather uniform in appearance in some areas. Spindle-shaped cell outlines could sometimes be ascertained. A tendency for denser accumulations of these tumor cells about vessels was noted. Several large areas with nuclei of highly varying appearance were located in the more centrally located portions of the tumor (Fig. 4). Nuclei here tended to be oval or spherical, varied considerably in size and sometimes appeared multilobed and distorted. Mitotic figures were numerous. Chromatin material of these nuclei stained heavily, irregularly and in many there appeared to be nucleolus-like structures. These cells were large and their outlines when visualized were pyramidal or stellate in shape.

A large necrotic zone bordering upon the left lateral ventricle occupied about one-third of the coronal diameter of the tumor. Amorphous granular material, cellular debris, including faintly visible erythrocyte outlines, and occasional nuclei were noted within this area.

The tumor was very vascular in its central portions where dilated arterioles packed with erythrocytes were prominent. Some capillaries and small arterioles showed a mild grade of endothelial proliferation. In vessels adjacent to the necrotic zone adventitial thickening and proliferation were prominent; occasional small vessels of this zone showed round-cell collections in the adventitial layer.

Diagnosis. Glioblastoma multiforme of septum pellucidum.

DISCUSSION

The clinical manifestations of tumors of the septum pellucidum were described by French and Bucy[4] as predominantly the result of local obstruction and compression. These included "episodes characterized by headache, occasionally visual and aural disturbances, and less frequently cataplectic-like weakness; mental disturbances, particularly related to memory; occasionally convulsions; less commonly unsteadiness or weakness of movement or numbness." Objective signs included "mental defects, frequently papilledema, less commonly paresis, paresthesias, ataxia and defects of movement or tonus."

FIG. 3. Coronal section through mid portion of tumor (hematoxylin and eosin).

Sprofkin and Sciarra[13] suggested that Korsakoff's psychosis, characterized by partial or complete disorientation, confabulation, retention defect and variable degree of amnesia, is apt to occur in brain tumor patients in whom there is extensive involvement of the "deeply situated midline structures" together with some underlying personality factor. The frequent incidence of mental abnormality particularly related to memory, mood and initiative was noted by French and Bucy[4] in those cases in which tumor of the septum pellucidum was sufficiently large to obstruct the ventricles, invade the frontal lobes or involve the corpus callosum.

Although it has been stated[4] that tumors of the septum pellucidum predominantly affect young adults, exceptions have been encountered. Our patient was 72 years of age, while Case 2 of Sprofkin and Sciarra[13] was 62 years of age, and Case 1 of Nistri[10] was 59 years of age. The review of French and Bucy[4] summarizing the data derived from 31 cases from the literature as well as from 5 of their own cases suggested that tumors of the septum pellucidum are much more common than realized. We have been able to find reports of 20 additional cases which are listed in a tabular form similar to that used by French and Bucy (Table 1).

Calcification of the neoplasm as was present in 5 of 32 cases in the French and Bucy review was not detected in our case either in skull x-rays or in postmortem roentgenographic studies of the brain. We have not found mention of calcification in radiological or in microscopic descriptions in the

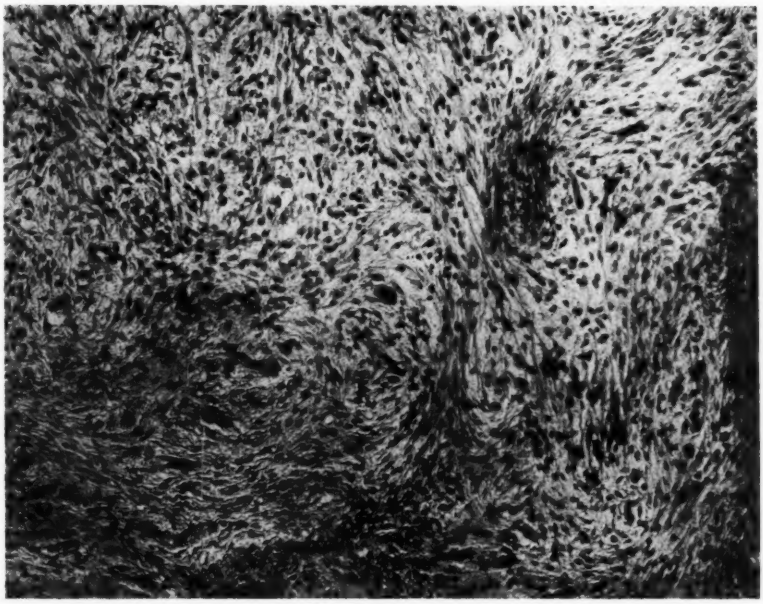

FIG. 4. Microscopic view of central part of tumor (hematoxylin and eosin).

other cases listed in Table 1, although the data in the first 7 cases are relatively inadequate. The importance of ventriculography in making a clinical diagnosis of tumor of the septum pellucidum has been repeatedly stressed.[2,4,8]

The tumor in our case was a glioblastoma multiforme. In the 20 additional cases collected from the literature the following types of tumor were included: fibrillary astrocytoma, oligodendroglioma, isomorphic glioblastoma, astrocytoma and ependymoma. A wide variety of gliomas was also described in the French and Bucy series including these added types: subependymal astrocytoma, spongioneuroblastoma, astroblastoma, and spongioblastoma unipolare. Tumors arising in the septum pellucidum resemble those arising within the cerebral hemispheres generally. Their variety would appear to be related to the finding of Bailey and Cushing[1] that periventricular areas are particularly important as the site of origin of many gliomas, and the report of Globus and Kuhlenbeck[5] that immature cell elements with presumed neoplastic potentialities are frequently found within the subependymal cell plate extending into the septum pellucidum.

Successful surgical resection of tumors of the septum pellucidum was stated by French and Bucy[4] to have been accomplished in at least 5 cases. An additional successful operation was claimed by Škorpil, Kunc and Macek,[12] who stated that 6 months after operation, the mental and neurological findings were normal. The possibility of a beneficial effect from x-ray

TABLE 1

Reported by	Year	No.	Operation or Necropsy	Diagnosed	Notes
Winkler & Rotgans[15]	1902	1	Necropsy	"Sarcome"	Death after negative cerebral exploration.
Vincent, Giroire & David[14]	1925	2	Necropsy	—	Quadriplegia in flexion, hyperalgesia.
McLean[9]	1936	3	Necropsy	Fibrillary astrocytoma	Right unilateral hydrocephalus.
Foerster[3]	1937	4	Necropsy	Glioblastoma	4 of 80 glioblastomas among 552 verified tumors.
		5	Necropsy	Glioblastoma	
		6	Necropsy	Glioblastoma	
		7	Necropsy	Glioblastoma	
Löwenberg & Waggoner[7]	1939	8	Necropsy	Oligodendroglioma	Feebleminded, disoriented.
		9	Necropsy	Oligodendroglioma	Dizzy spells and convulsions 14 yrs.
Scherer[11]	1940	10	Necropsy	Oligodendroglioma-astrocytoma	
Nistri[10]	1947	11	Necropsy	Isomorphic glioblastoma	Infiltrated genu; almost obliterated frontal horns of lateral ventricles.
		12	Necropsy	Isomorphic glioblastoma, cystic	Bitemporal hemianopsia; enlarged sella turcica.
Lowman, Shapiro & Collins[8]	1948	13	Necropsy	Astrocytoma	Left frontal lobe resected for decompression. Died 2 days later.
		14	Operation	Fibrillary astrocytoma	Roentgen therapy; partial resection.
		15	Operation	Oligodendroglioma?	Biopsy; roentgen therapy with remarkable improvement.
Škorpil, Kunc & Macek[12]	1950	16	Operation	Oligodendroglioma	Successful operation. Patient "normal" 6 mos. later.
Davidoff & Epstein[2]	1950	17	Operation	Astrocytoma	
Sprofkin and Sciarra[13]	1952	18	Necropsy	Glioblastoma	Korsakoff's psychosis; death 1 mo. after frontal craniotomy.
		19	Necropsy	Glioblastoma	Epileptic 35 yrs.; recent Korsakoff's psychosis.
Kernohan & Sayre[6]	1952	20	Necropsy	Ependymoma	Tumor projected into each lateral ventricle, right more than left; internal hydrocephalus of left lateral ventricle.

treatment should not be overlooked. In Case 3 of Lowman, Shapiro and Collins[8] the patient received two courses of roentgenotherapy following exploration and biopsy of a septum pellucidum tumor, with "remarkable improvement," remained free of complaints during the next 6 years and thereafter ceased to return for follow-up treatment. In a case reported by Davidoff and Epstein[2] (Case 78) ventriculography disclosed an irregular midline tumor shadow projecting unevenly into the lateral ventricles, that toward the right being much greater. The impression of the authors was that they were dealing with a solid tumor of the septum pellucidum, although this was apparently not verified. Following subtemporal decompression, a course of roentgen therapy was given, after which there was disappearance of headaches, absence of fainting spells and marked recession of optic disc swelling.

SUMMARY

1. The clinical and pathological features of a 72-year-old woman with a glioblastoma multiforme of the septum pellucidum are described.

2. An additional 20 cases of tumor of the septum pellucidum are cited from the literature, raising to 57 the number of verified tumors of the septum pellucidum that have been reported.

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USE OF POLYVINYL SPONGE IN NEUROSURGERY

HENRY W. DODGE, JR., M.D., JOHN H. GRINDLAY, M.D., WINCHELL McK. CRAIG, M.D., AND PAUL J. ROSS, M.D.

Section of Neurologic Surgery and Section of Surgical Research, Mayo Clinic and Mayo Foundation, Rochester, Minnesota*

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ONE of the primary problems facing a neurosurgeon in operative procedures necessitating sacrifice of the dura mater or requiring repair of cranial or spinal dural or bony defects is the assurance of watertight closure of the cerebral or spinal dural envelope. Polyvinyl plastic sponge has been used recently with success in various surgical procedures.[1–3] It occurred to us that such material, namely, wettable plastic sponge with numerous interstices through which blood vessels and connective tissue can grow to form a neomembrane of connective tissue and sponge, might be useful in its application to some of the problems encountered in the practice of neurosurgery.† To this end a series of dogs was operated on in an attempt to elucidate the mechanism by which this material is incorporated into living tissue in and about the nervous system.

PRESENT STUDY

During the past 3 years, portions of spinal or cranial dura mater have been excised in 12 dogs. The portions excised were of various sizes and were situated over normal and also over traumatized cortex. Polyvinyl sponge was placed over normal and traumatized nervous tissues in the dural defects thus created in both the cranium and spinal cord. Observations were made at necropsy and at reoperation as to the microscopic and gross pathologic changes encountered during periods ranging from 6 months to 2 years (Figs. 1 and 2). It is our opinion that polyvinyl sponge is a useful and worthwhile substance for repair when it is properly used for correction of defects in the covering of the nervous system in animals. This type of sponge also has been placed in and about the nervous system in 27 patients during the past 2 years.

COMMENT

In the use of new synthetic materials in surgery, it is important to be cognizant of the disadvantages as well as the advantages of the material to

* The Mayo Foundation is a part of the Graduate School of the University of Minnesota.

† The polyvinyl sponges used in this study were kindly furnished by the manufacturer, Ivano, Inc., Chicago, and are available from Clay-Adams, Inc., New York City.

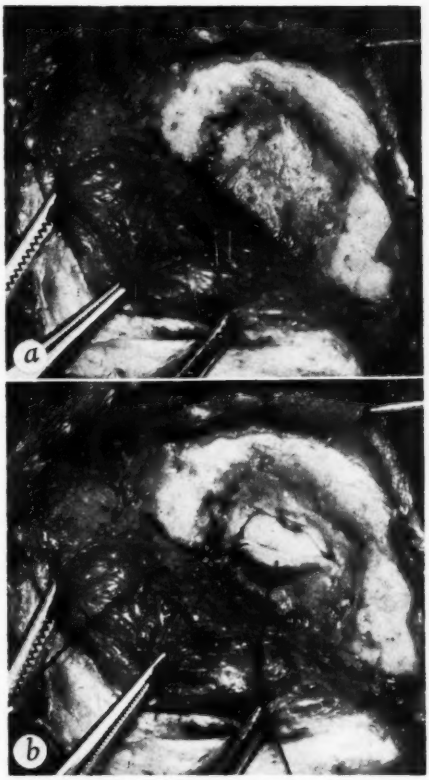

FIG. 1. (*a*) Neodura formed in a dog by polyvinyl sponge placed in bony and dural defects after right craniectomy and removal of dura mater over nontraumatized brain 16 months previously. (*b*) Neodura in same dog, demonstrating smooth, glistening, normal-appearing brain underlying sponge.

the patient and to the surgeon who uses it. Therefore, on the basis of our experience with polyvinyl sponge, we consider that this material is a useful substance when employed in certain situations. This sponge can be used as a watertight dural substitute when it is sewed in place in dural defects in the spinal cord and cranial cavity, provided edematous brain or spinal cord is not tightly approximated to the cut edges of the dural defect if the piarachnoid has been disrupted. It may be utilized satisfactorily in the repair of conditions producing cribriform rhinorrhea or cerebrospinal otorrhea.[5] It may be used for the performance of orbitoplasty after transcranial removal of orbital tumors if the defect cannot be repaired satisfactorily by means of the usual stainless-steel or acrylic plates.[4] It may be employed for reinforcement of walls of intracranial aneurysms or for closure in the management of certain meningoceles.

Effective and watertight closure after high cervical laminectomies, suboccipital craniectomies or combined cervico-occipital operations may be achieved by use of polyvinyl sponge in occasional difficult cases. The removal of malignant lesions in and about the nervous system may produce operative defects in which the plastic sponge is helpful for repair. We have noted that the involved area may leak cerebrospinal fluid for several days after repair of dural defects by use of these sponges. When invasion of the sponge by fibrous tissue takes place, the closure becomes satisfactorily watertight.

One of the most important contraindications to the use of polyvinyl sponge is the presence of considerable edema or trauma of the brain or spinal cord, with disruption of the piarachnoid. Gliosis through the lacerated pia mater into the sponge may take place more rapidly than does the desired

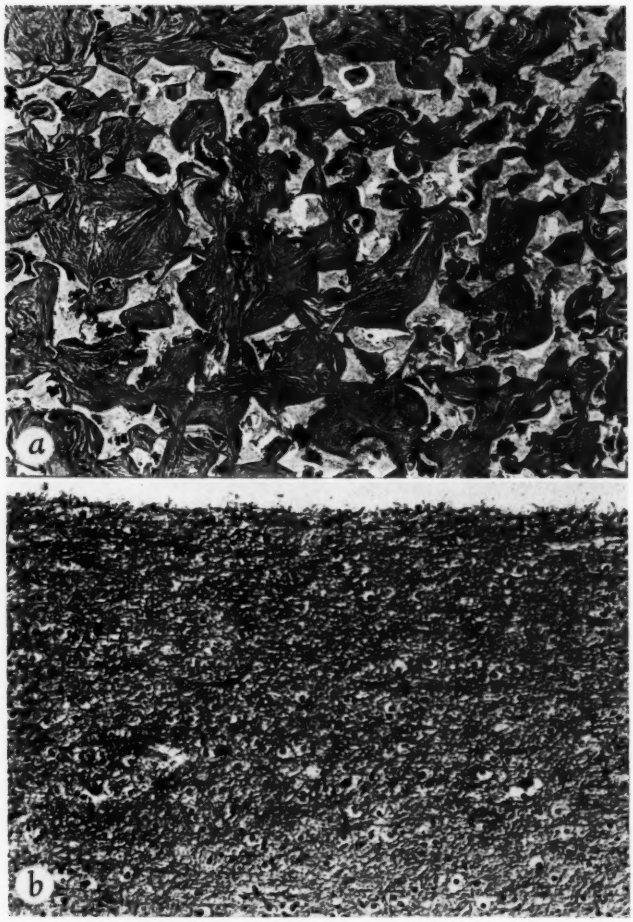

FIG. 2. (*a*) Photomicrograph of neodura formed by polyvinyl sponge demonstrating growth of normal collagenous tissue into interstices of sponge (hematoxylin and eosin, ×30). (*b*) Appearance of nontraumatized brain directly under area of dural repair (hematoxylin and eosin, ×145).

growth of connective tissue into the sponge from the edges of the cut dura mater. This leads to adhesions. The presence of contamination or infection is a contraindication to its use. Should the surgeon desire to use polyvinyl sponge in an area over traumatized nervous tissue, the injured nervous substance should be covered first with inert material, such as animal membrane. Peritoneum from sheep has been used for such a purpose. The sponge should perform efficiently in these instances if this precaution is used.

No reactions have followed placement of this material in the cranial or

spinal cavities, and to date we have had no incidence of infection. A few patients have displayed slight increases in temperature for several days during the immediate postoperative period. In no case has the sponge been extruded, and in no case in which we have employed the sponge and later had an opportunity to examine it have we encountered the foreign-body encystment so frequently seen with many substances placed in the body.

It is our practice, as is done when any foreign body is placed in or about the nervous system, to use penicillin prophylactically after the operation. At the time of incorporation of this sponge into the wound, an instillation of 20,000 units of aqueous penicillin is made into the wound and the entire length of the sponge is moistened with this solution. We have used sponge varying from 1 to 3 mm. in thickness and of the desired dimensions to fit the defect. However, the sponge may be cut to any size depending on the needs of the individual surgeon. The material was sterilized by boiling it in water.

SUMMARY

On the basis of both experimental and clinical experiences at the Mayo Clinic, polyvinyl sponge appears to have a place in neurosurgery in the replacement or reinforcement of the natural tissues covering the central nervous system. Polyvinyl sponge should not be placed over infected, edematous or traumatized nerve tissue. As in the use of other foreign materials in surgery, the indications and contraindications for the insertion of polyvinyl sponge must be well recognized.

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RESULTS OF RADIOACTIVE ISOTOPE ENCEPHALOGRAPHY

IN PATIENTS WITH VERIFIED INTRACRANIAL TUMORS

LOYAL DAVIS, M.D., AND THOMAS CRAIGMILE, M.D.
Department of Surgery, Northwestern University Medical School, Chicago, Illinois

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SINCE 1949, we have utilized radioactive isotope encephalography in the majority of patients we have observed who were suspected of having an intracranial tumor. The scanning surveys were made following the administration of radioactive di-iodo-fluorescein, radioactive sodium iodide, or radioactive human serum albumin. An earlier report of the results of isotope encephalography concerned itself with findings in normal patients and those with verified intracranial tumors, suspected intracranial tumors, craniocerebral injuries, inflammatory lesions, and various vascular abnormalities.[1] The present study is confined to the results of the isotope study in patients with intracranial tumors verified at operation, or at the time of postmortem examination, by means of radioactive di-iodo-fluorescein and sodium iodide.

A total of 1251 patients have had isotope encephalographic studies. Among this number of tracings, 200 have been obtained upon patients in whom a primary, or metastatic, intracranial tumor has been verified microscopically. In this group, 193 tumors were verified at operation and 7 at autopsy.

Of the 200 patients studied, 159 underwent isotope encephalography following administration of radioactive di-iodo-fluorescein and 41 after the injection of the radioactive sodium iodide. With an insignificant number of exceptions, all of the individuals studied were adults and no attempt was made to evaluate the results upon the basis of the age of the patient. There has been no evidence that the sex of the individual undergoing testing is of importance. No attempt was made to compare the results of the examination in persons with a metastatic tumor from any particular primary site with those with neoplastic nodules from any other initial location. As might be expected, the predominant metastatic tumor found was a bronchogenic carcinoma.

Techniques employed in radioactive isotope encephalography have been described in detail elsewhere. Following intravenous administration of the radioactive substance, determinations of the degree of emanation of radioactivity are made at thirteen specific, diametrically opposite points on each side of the head. In addition to these twenty-six areas scanned, six midline readings are made.

Initially the end-window Geiger-Mueller tube with a suitable counting device and a graphic recorder of counts per minute were utilized. During recent months we have employed the more nearly accurate scintillation counter. No effort to separate the results using the two techniques has been made in this study.

Previous studies of the use of radioisotopes in the localization of neoplasms within the cranium have shown that tumors of certain histopathological nature as well as those in certain specific sites do not assimilate radioisotopic substances to a more than minimal degree. No tumor in this category was excluded from the study.

A critical analysis of the results of examination in patients suffering from primary neoplasms was not difficult after certain criteria concerning classification were established. Evaluation of our findings produced the following groupings: (1) accurate localization evidenced by an abnormally high focal concentration of the radioactive substances; (2) a somewhat more diffuse concentration of activity on one side of the head without evidence of any focal increase; (3) a generalized increase in radioactivity bilaterally, often involving both the supra- and infratentorial regions; (4) tracings displaying entirely normal concentrations in all areas; and (5) tracings revealing a focal increase in radioactivity at a site not overlying the later verified tumor.

Evaluation of the results in patients with metastatic intracranial tumors was not such a simple matter. In patients with a suspected, relatively large, symptom-producing nodule, there was the possibility that other clinically silent lesions existed which would influence the tracing. Even in those few cases that came to autopsy not long after examination, the presence of multiple metastases of widely varying size and situation made analysis of the results of the radioactive isotope encephalogram difficult.

The interpretation of a focal increase in radioactivity is simple and apparent. When comparable areas on the two sides of the head display such an elevation, one may assume that the lesion is located near the midline. For example, a bilateral increase in amplitude of radioactivity on the tracing in the anterior temporal area is interpreted as being indicative of the presence of an organic lesion in the region of the hypophysis or the rostral portion of the brain stem.

It has been postulated that the degree of up-take of a radioactive substance by an intracranial tumor depends upon certain interrelated factors, specifically the degree of vascularization, the degree of malignancy, and an increase in capillary permeability in the particular tumor encountered.

The average amount of di-iodo-fluorescein administered was 1.1 millicuries while that for sodium iodide was 300 microcuries. In no instance was any untoward reaction to the injected isotopic preparation experienced.

RESULTS OF STUDIES AFTER ADMINISTRATION OF RADIOACTIVE DI-IODO-FLUORESCEIN

Of the 159 patients who were studied following the administration of radioactive di-iodo-fluorescein, a primary intracranial tumor was verified in

138. With no attempt made to classify results according to specific tumor types, accurate localization of the tumor site was achieved in 85 of the 138 cases, or 61.6 per cent. Three patients displayed a diffuse increase in concentration of radioactivity in the involved hemisphere. Nineteen individuals (13.7 per cent) produced tracings showing a generalized increase in activity above the normal limits of amplitude. No abnormality in the tracing was discovered in 27 instances (19.5 per cent). In 4 patients, a focal increase in radioactivity was found at a site some distance from the later verified neoplasm with no abnormality being noted in the region of the tumor.

Analysis of the results of the dio-iodo-fluorescein study in patients with certain of the more frequently encountered primary neoplasms corroborates the opinion that the dye has a greater affinity for certain pathological types than it does for others.

The *glioblastoma multiforme* was the most frequently encountered primary tumor. It was present in 48 of the 138 patients with intracranial tumor who were examined by this method. The isotope study produced accurate localization in 27 of the 48 cases, or 56.3 per cent. A lateralizing concentration of the dye to the involved hemisphere without evidence of a focal increase in activity was found in 2 patients, while 11 exhibited a generalized diffuse increase in radioactivity. The isotope encephalogram was entirely normal upon 8 occasions.

As earlier investigators have indicated, the relatively avascular *astrocytoma* produced more inaccurate isotope tracings than any other tumor in the present series. Following the injection of di-iodo-fluorescein, precise localization of the site of the neoplasm was found in only 13 of 31 patients, a rather disappointing 41.9 per cent. Of the 4 cases displaying misleading positive findings in the entire group of 138 surveyed after administration of di-iodo-fluorescein, 3 occurred in the presence of an astrocytoma. The examination produced a generally increased, non-localizing tracing in 6 instances. Eight tracings were normal.

The isotope study produced a precise localization of the tumor in 4 of 6 patients with an *oligodendroglioma*. Of the other 2 patients in this category, one displayed a general increase in activity but no areas of focal elevation and the other tracing was within normal limits.

The di-iodo-fluorescein examination accurately diagnosed the presence and site of 3 of the 4 *medulloblastomas* verified. No abnormality was found in the tracing of the fourth patient. One *papilloma* of the *choroid plexus* was precisely located but another failed to exhibit any ability to concentrate the isotope. A third individual with such a lesion produced a positive, but misleading tracing.

The results in the cases of *meningioma* were more satisfactory. There were 24 patients with such a lesion and the site of the tumor was located in 19, or 79.1 per cent. A diffusely increased degree of radioactivity occurred in 1 instance. Tracings in 4 individuals were not abnormal.

Eight of 10 *chromophobe adenomas* examined were accurately located by

means of the radioisotope study. This is a more encouraging figure than others have reported. The only *eosinophile adenoma* encountered in this study was accurately localized as was the single *cerebellar hemangioblastoma* surveyed.

Five patients with an *acoustic neurinoma* were studied and precise localization was obtained in 4 instances. The presence of 1 of 2 *craniopharyngiomas* was discovered by this method.

The results of the isotope study, utilizing di-iodo-fluorescein or sodium iodide, in the presence of intracranial metastases cannot be evaluated with ease and confidence as can the findings in cases of primary intracranial tumors.

Twenty-one patients with solitary, or multiple, metastatic intracranial nodules were studied following the administration of radioactive di-iodo-fluorescein. Accurate localization of a verified solitary tumor was obtained upon 10 (47.6 per cent) occasions. Diffusely increased radioactivity was found in 5 patients undergoing craniotomy for removal of a clinically evident, single tumor mass. It is quite likely that one, or perhaps more, smaller nodules were also present at the time of examination, thereby contributing a confusing aspect to the problem of interpretation of the isotope encephalogram. In 1 case, verified at autopsy, there were numerous metastatic lesions. The tracing in this patient was one of generally increased amplitude, certainly an expected finding in the presence of multiple intracranial metastases. Normal tracings were produced by 5 of the 21 patients with metastatic tumors. The 16 individuals presenting tracing abnormalities of varying types represent approximately 76 per cent of such patients examined.

RESULTS OF STUDIES AFTER ADMINISTRATION OF RADIOACTIVE SODIUM IODIDE

During 1952 and 1953 approximately half of our patients suspected of having an intracranial tumor received an isotope encephalographic study after the injection of radioactive sodium iodide, usually in the dosage of 300 microcuries.

Forty-one intracranial tumors, 36 primary and 5 metastatic, have been microscopically verified in patients who underwent this method of evaluation. In patients with a primary neoplasm, evidence of its presence and accurate localization of its site were obtained in 19 of the 36 cases (52.8 per cent). Thirteen of these 36 individuals (36.1 per cent) produced tracings of normal amplitude. Three tracings exhibited a generalized increase in radioactivity with no focally concentrated abnormalities. One tracing revealed a focal increase in activity at a point some distance from the actual site of the later verified tumor. These results in cases of primary intracranial tumors, when compared to those obtained with radioactive isotope encephalography using di-iodo-fluorescein, suggest that the latter substance is a more reliable diagnostic agent. However, a larger group of patients must be surveyed before such a conclusion is made.

In 21 patients in whom a glioblastoma multiforme was verified, accurate localization following the use of radioactive sodium iodide was obtained upon 13 occasions (62 per cent)—a greater figure than that realized following the use of di-iodo-fluorescein in patients with a similar tumor. A diffuse, nonfocalizing increase in radioactivity was seen in 2 instances. In this group, 6 isotope studies were within the limits of normal.

Four patients with astrocytoma were examined following the injection of sodium iodide. The lesion was accurately located in 2 of these individuals while a third displayed a diffuse increase in radioactivity. The tracing of the fourth failed to reveal any evidence of abnormal concentrations of the isotope.

Of the 3 meningiomas studied by this method, only one showed an accurately localizing increase in concentration. The remaining 2 produced no deviation from the normal pattern. One of 2 chromophobe adenomas surveyed was accurately localized by sodium iodide studies. No abnormality was found in the other.

Two patients with craniopharyngiomas were studied and accurate identification of the tumor site was made in each. The presence of a pinealoma failed to produce any deviation from the normal in 1 instance. A normal tracing resulted in 1 individual with a cerebellar hemangioendothelioma and in another with a medulloblastoma. One patient with a small cortical angioma displayed radioencephalographic evidence of a lesion of the opposite hemisphere.

The results of radioisotope studies using sodium iodide were most disappointing in the presence of metastatic intracranial tumors. Five patients with lesions of this nature were examined and normal tracings resulted upon 4 occasions. In the other instance, the tracing revealed a generalized increase in activity in a patient with an apparently solitary metastatic nodule.

SUMMARY

The results of isotope encephalography, performed after the administration of radioactive di-iodo-fluorescein or radioactive sodium iodide, in 200 patients with verified primary or metastatic intracranial tumors have been reviewed. Primary intracranial tumors were found in 174 cases while metastatic neoplastic lesions were encountered in 26 instances. The original end-window Geiger-Mueller counter was used in the majority of the studies, but recently a more nearly accurate scintillation counter has been utilized. No attempt was made to classify the results on the basis of the counting device used.

Analysis of the results of isotope encephalography, using di-iodo-fluorescein initially, and in the greater number of cases, and sodium iodide more recently and in fewer instances, reveals a slightly higher incidence of accurate findings following the use of the former substance. In individuals with primary intracranial tumors, utilization of di-iodo-fluorescein resulted in accurate localization of the verified lesion in 61.6 per cent of the patients

examined. The use of radioactive sodium iodide gave a precise indication of the site of the neoplasm in 52.8 per cent of all patients examined by that method.

In 21 patients with metastatic intracranial tumors, studies following administration of di-iodo-fluorescein showed evidence of the presence of an organic lesion in approximately 76 per cent. Precise localization of a solitary metastatic nodule was obtained in 47.6 per cent of the patients examined.

The results of the examination following injection of radioactive sodium iodide in 5 individuals with metastatic lesions were far from encouraging. One person with a solitary nodule displayed a generalized increase in radioactivity without evidence of focal concentration. All others similarly examined showed no abnormalities in their tracings.

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ANTERIOR CINGULECTOMY IN MAN

J. LE BEAU, M.D.
Hôpital Lariboisière, Paris, France

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THE first series of bilateral anterior cingulectomies in man was reported in 1949.[13,14] Since then the operation has met with increasing success in various clinics. It seems worth while to present at this time the therapeutic and psychological results in the first 50 cases in our series. This group does not include 18 "mesial undercuttings."

Just before the War we were studying the aftereffects of the total removal of gliomas of the anterior half of the corpus callosum.[4,29] The rarity and insignificance of the so-called postoperative frontal syndrome was a first point. A second was the postoperative disappearance of "imperviousness."[1] This apathetic state, then, is probably caused not by callosal interruption, but by bilateral pressure on the mesial frontal surface.

Later, in the treatment of some states of agitated behaviour, it became possible to compare the results of classical lobotomy with those of limited resection of the convexity, or topectomy, introduced by Pool.[21] Topectomy seemed to us definitely less successful when the agitation and violence were apparently not related to anxiety. Perhaps, then, it would be necessary to resect the mesial aspect of the frontal lobe in order to deal with an *active* psychomotor component, different from the passive element in cases of anxiety and intractable pain.

In physiological experiments (cingular resections in monkeys) Smith[25] and Ward[28] observed a postoperative state of tameness and placidity. That was a further incentive to perform cingulectomy in man, even without Papez's[19] well-known theory of the importance of the temporodiencephalo-cingular circuit in emotions. At least it was suggestive that the thalamo-cingular fibers came from the anterior nucleus, while the dorsomedial nucleus connected with the granular frontal cortex. Accordingly, when we embarked on a program of systematic study of the clinical and psychological effects of different limited frontal operations, the comparison between granular areas 9 and 10, and agranular area 24, i.e. between topectomy and anterior cingulectomy, was given a high priority. The first cingulectomies were performed in 1948 and the main features relating thereto were described in successive papers from 1949 to 1953: clinical results in agitated behaviour and epilepsy,[5,6,7,13,14] and in psychoneuroses, especially obsessive;[9,10,11] detailed operative technique;[10,13,14] description of the special postoperative syndrome;[9,11,13,14] and objective psychological study.[11,15,16]

SURGICAL TECHNIQUE AND COMPLICATIONS

The technique has been described previously[10,13,14] and need not be repeated here. However, the following main points may be emphasized:

General or local anesthesia is used, according to the cooperation of the patient and the way in which corticography is performed.

A unilateral frontal bone flap (left or right) is made tangential to the longitudinal venous sinus, 2 cm. in front of the coronal suture and 3 cm. above the orbital ridge.

The left frontal lobe is retracted (often involving section of several subdural veins, but still *only on one side*) until the free edge of the falx is seen. Then the mesial faces of both frontal lobes are separated down to the corpus callosum, whiter than the surrounding convolutions and partly covered by the two pericallosal arteries giving off ascending branches to areas 8, 9 and 10.

When the genu is well freed, minute holes are pierced in the pia mater of the anterior limbic convolution or area 24, and through them the cortex is aspirated with a fine tube, thus respecting the ascending arteries and contributing to the selectivity of the operation. As both cingular gyri are visible under the falx, the cingulectomy is a bilateral operation with a unilateral approach.

Usually the operation is limited to the anterior part of area 24, 3 cm. long and 1.5 cm. high, but can involve area 25 below the genu 2 cm. more ventrally. This is the typical agranular resection. Often it involves some dysgranular cortex of area 32, 2 cm. more in front of the genu, and sometimes area 12 near the orbital level.

Narrow bands of gelfoam, soaked with lipiodol and then partly dried, are put over the resected areas, both for hemostasis and radiological landmarks (Fig. 1), although the genu is a well-defined structure, impossible to miss.

FIG. 1. Postoperative radiographs, frontal and lateral views: unilateral frontal flap, clips on dura mater; gelfoam with lipiodol shows cingulectomy.

Thus the operation is much more precise anatomically than any other psychosurgical technique. The only obstacle to selectivity is the unilateral section of some subdural veins, but this does not always happen, and even so there is never a complete interruption of the venous drainage. In view of the strict unilaterality of this slight venous drainage, we doubt very much it could leave a permanent significant effect.

The main vital risk in our operation seems to be the need of prolonged

general anesthesia in cases of extreme mental retardation with uncontrollable agitation. The only deaths in the series of 50 cases were in 2 children with such disorder (there was no abnormal hemorrhage). In another similar case tracheal intubation was followed by a laryngeal spasm and recovery followed tracheotomy. In 2 patients a transient hemiparesis was observed for 8–10 days. In another intense anemia developed on the 8th day and was cured with difficulty in 3 weeks. No other patient gave any reason for alarm, and indeed the absence of apparent mental disturbance was the main feature of the immediate postoperative course, as well as the absence of early or late epileptic fits in patients who were not epileptic before the operation.

CLINICAL RESULTS

The results are shown in Table 1. "Good results" mean: complete or nearly complete cure with useful activity in patients with a not too deteriorated preoperative intellectual level, and marked improvement with at least some activity in the cases of pronounced mental retardation.

To sum up, the results of anterior cingulectomy are good in the clinical syndromes of extraversion with irritability and violence, especially perhaps in chronic generalized epilepsy, but not in the excitation of psychopathic personality. They seem bad in the clinical syndromes of introversion with

TABLE 1

Clinical results of anterior cingulectomy

Diagnosis	No. of Cases	Good Results	Follow-up (years)
I. *Depressive states*			
a. with anxiety or pain (including 2 epileptics)	5	0	
b. with obsessive neurosis (including 1 epileptic)	4	3	3, 1, ¾
II. *Excited states*			
a. with hysteria (including 2 epileptics)	3	2	3, 2
b. with psychopathic disorders (including 1 epileptic)	3	0	
III. *Psychoses with violence*			
a. dementia epileptica	2	1	1½
b. schizophrenic syndrome	2	2	5, 3
IV. *Epilepsy*			
a. subnormal mental state	5	3	4, 3½, 2
b. irritability and violence	9	7	5½, 4, 3½, 3½, 2½, 1, ½
V. *Mental retardation and agitation*			
a. with epilepsy	7	5	3, 2, 1½, 1½, ½
b. without epilepsy	4	3	3½, ¾, ½

chronic anxiety and pain. They are good in the obsessive compulsive neurosis in which it seems there is an active component added to the classical anxiety.

Thus schematically presented the results stand in sharp contrast to those of topectomy of the dorsal granular cortex of areas 9 and 10. The latter operation in our experience[8,11] is mostly effective in cases of intractable pain, anxiety neurosis, and depressive states, in which it is generally justified to describe a clinical introversion syndrome; but it often fails in states of

excitation, agitation and violence, in which clinical extraversion seems predominant.

The mesial undercutting, of which we have had 18 cases since 1950, is in a way an intermediary operation, excluding part of the granular cortex of areas 9 and 10, and areas 32 and 24 as well. We found it especially effective in obsessive compulsive neurosis (as much as cingulectomy and more than dorsal topectomy), and we would try it first in confirmed schizophreniacs with agitation and violence, rather than cingulectomy.

We feel entitled to conclude that the clinical results suggest an opposition between the effects of ablation of mesial agranular and dorsal granular frontal cortex.

ANALYSIS OF POSTOPERATIVE SYNDROME

Four years ago our experience with anterior cingulectomy was sufficient to allow us to write that, in marked contrast to the "convexity" patients, the classical euphoric and careless behaviour was *not* present after cingulectomy. During the first postoperative days, the patients are often quieter, and seldom slightly agitated. But there is no mental confusion—they are very well aware of the surroundings and events with the proper amount of attention; there is no euphoria, no irritability, no sphincteric incontinence. We could conclude on the weight of such clear-cut differences that behaviour was modified in perhaps specific ways by those two types of limited frontal resection.[13,14]

A study of the immediate postoperative course of the not too mentally retarded patients yielded the following figures: out of 80 convexity operations, a clinical postoperative syndrome was present in 53 (63 per cent); while out of 40 cingulectomies it was found in only 6 patients (15 per cent), and then nearly always when the resection went as far down as the region of area 12. The figures for orbital operations and mesial undercuttings have been reported previously, together with details of both the convexity operation and cingulectomy.[9,11] The larger numbers presented now further support our first observations and conclusions.

The convexity postoperative syndrome is mostly one of uninhibited behaviour, often similar to slight drunkenness. It deserves the *clinical* name of extraversion. On the contrary, after cingulectomy, the patients seem quieter and more restrained. Perhaps it can be said that their behaviour is one of *clinical* introversion. Thus there is a suggestive analogy between the behaviour during the immediate postoperative period and the long-term therapeutic results, as seen above. But it should be emphasized again that there is no correlation between the final result and the apparent *intensity* of the immediate syndrome.[9]

PSYCHOLOGICAL RESULTS

In 1950, thanks to Professor Alfred Meyer, we became acquainted with the psychological method of objective behaviour tests developed at the Maudsley Hospital in London by Eysenck and his collaborators, notably

Mrs. Petrie. There was at last the possibility of making quantitative psychological studies of the noncognitive dimensions of personality. We decided then to submit our patients in Paris before and after the operation to a series of objective tests strictly following Eysenck's technique. This long and difficult work would not have been possible without the constant help of Mrs. Petrie, who trained our psychologists and worked out all the statistical results.

The personality measures used in these studies are related to the following dimensions of personality: intelligence, extraversion, neuroticism, psychoticism.[2,3] Let us remark at once that those terms have a defined *operative* meaning and should not be confused with the vague *clinical* meaning. In practice, the groups of tests objectively differentiate between the neurotic and the non-neurotic, the psychotic and the nonpsychotic, the extravert and the introvert.

The main results have been published before[11,15] and more recently at the International Neurological Congress in Lisbon:[16]

(1) The convexity operations are followed by changes in the direction of decreased neuroticism and increased extraversion, confirming the studies of Mrs. Petrie on lobotomies.[20] There is no indication of decreased psychoticism. There is no lowering of intelligence.

(2) The cingulectomies are followed by changes in the direction of slightly decreased neuroticism, but there is no indication of increased extraversion. Psychoticism has decreased. There is no lowering of intelligence.

The psychological studies afford striking confirmation of the clinical inferences. After selective surgery there are definite indications of specific effects, at least when cingulectomy (mostly agranular) and convexity resection (granular) are compared. Furthermore, cingulectomy is on the average less extensive than convexity resection, but nevertheless it is followed by more pronounced changes in decreased psychoticism than any other operation, including standard lobotomy.[16] Finally the significance of these findings is enhanced by the nature of our material: mostly patients with intractable pain for the convexity operation and mostly chronic epileptics for cingulectomy; in other words the observed changes are in all likelihood related to the resection of the frontal cortex and not to the cure of an evolutional mental disease.

Needless to say these conclusions in favor of the specific or qualitative theory of frontal lobe mental functions, are in no way a negation of the possibility of quantitative action as well. But such an abstract discussion is irrelevant. The only scientifically satisfying attitude is to find an objective method of estimating the relative importance of the qualitative and quantitative factors. The psychological techniques advocated here appear to be a definite advance in combination with selective frontal surgery.

ELECTROENCEPHALOGRAPHIC STUDIES OF CINGULECTOMIES

The largest group in our series of cingulectomies are the epileptics, with pronounced disorders of character, chiefly irritability and violence. Thirty-

four cingulectomies were performed in cases of chronic generalized medically irreducible epilepsy. The results in the main confirm those previously published:[5–7,10,13,14] cingulectomy is nearly always effective against the irritability, anger, aggressiveness, violence, permanent or intermittent, of chronic epilepsy, and this is often enough for gratifying social rehabilitations. Epilepsy itself was never made worse; usually it was somewhat improved, sometimes it was completely cured. This for the clinical side.

On the electric side, corticography never disclosed focal activity in the cingular or precingular areas, and for this reason we do not perform it any more as a routine, in order to shorten the operation.

A detailed study of the EEG was carried out and in spite of the many well-known causes of errors in the estimation of the results in such a disease as chronic epilepsy,[10] it is interesting to give here the main findings, a detailed account of which is in press.[12]

In chronic clinically generalized epilepsy, some focalized unilateral predominance was observed in a few instances, but in only 2 cases is it perhaps legitimate to discuss a surgically localized epilepsy. There was no indication for a focal operation in any of the others.

The first postoperative EEG (less than 1 month) shows transitory alterations, more often temporal than purely frontal, contrasting again with the convexity operations. Later, after more than 1 year, about 45 per cent of the patients are much improved and 3 have a normal EEG. About 30 per cent have a comparable EEG, and 30 per cent seem worse. This, again, refers to the EEG findings and not necessarily to the clinical evolution.

Among the non-epileptic patients, in 1 case only were permanent postoperative alterations disclosed, probably because there was an operative injury of the convexity. In practice we feel the risk of permanent epilepsy after cingulectomy is much less than after lobotomy or even topectomy of the convexity.

DISCUSSION

(1) *Clinical and Psychological.* Before our first publication, very few similar operations had been performed: one by Pool, and two limited cingular undercuttings by Ward, all in cases of severe schizophrenia, with no appreciable result. But later other reports appeared in print. Only one concerns cingulectomy properly, from Cairns' clinic in 1952:[30] the technique, the postoperative observations and the main results are nearly the same as ours. However, in this series more schizophreniacs are found (with no lasting successes) and there were no operations in epileptics with irritability and violence. Personality changes in a more recent study[27] (of only 8 patients) were said to consist of a reduction of inhibition, perserveration and self-concern; it is of course always difficult to evaluate nonsurgically defined concepts, but we consider that these findings do not agree well with our own conclusions, which suggest clinically augmented introversion and restraint. They agree better with the diminution of neuroticism and psychoticism. The reduction of anxiety, which seems important to the Oxford workers, is not a specific result of cingulectomy.[10]

Other so-called *mesial* operations are from time to time implicitly discussed as cingulectomies. All of them are undercuttings of both granular and agranular cortex and do not seem to give the same results as the cortical resection of the cingular region. Scoville's[23] technique and our own mesial undercutting are included here; even Livingston's[18] operation, though more limited, cannot be considered as a selective cingular undercutting; and the limited coagulation recommended by Grantham is very likely to interrupt the thalamo-frontal bundle, therefore not deserving the name of a selective mesial section.

(2) *Physiological.* Stimulation of the anterior cingular region both in animal and in man yields autonomic effects.[22,25,28] Furthermore, it has a generalized regulatory action on the cerebral cortex.[17,24] We never observed any significant autonomic change after cingular resections, which is not surprising if one considers the other important cortical components (uncus, posterior orbital . . .). But the effects of cingulectomy on clinical epilepsy and on the EEG have perhaps a deep physiological significance. In that respect it is interesting to note that the neurosurgical inferences in man were published even before the first experimental results, which thus afford objective confirmation.[13,14,17] Nevertheless one should remember there is no disease in which the action of any new procedure is more difficult to estimate than epilepsy, because it is in practice impossible to follow the patient for a significant length of time under *exactly comparable* conditions.

Whether the effect of cingulectomy upon epilepsy depends upon the improvement in character or vice versa is open to question; both possibly depend on a common factor and, generally speaking, the mental changes following cingulectomy are more constant than the beneficial action on epilepsy itself. A recent important experimental work in cats[26] gives suggestive indirect confirmation of the different functions of the cingular and granular cortex: after destruction of the anterior nuclear thalamic complex—connected with the cingular areas—the cats are nicer, more gentle, and the threshold for rage is raised; after destruction of the dorsomedial nucleus—connected with the granular frontal cortex—the cats are more irritable with less motor activity, and the threshold for rage is lowered. Here again it would be gratifying if neurosurgery were to lead the way to experimental physiology.

SUMMARY

1. After an account of its introduction and development, the technique of anterior cingulectomy is described.

2. A series of 50 cases is reported. The best clinical results are found in cases of intractable irritability, aggressiveness, violence, and agitation, especially when associated with chronic epilepsy. Patients with obsessive-compulsive neurosis also react very favorably to cingulectomy. The follow-up period extends from $5\frac{1}{2}$ years to 6 months.

3. Cingulectomy is seldom followed by a significant postoperative clinical

syndrome during the first weeks, in contrast with the "frontal" postoperative syndrome often observed after topectomy of the convexity.

4. A psychological study, with objective behaviour tests, discloses after cingulectomy no lowering at all of intelligence, no indication of augmented extraversion, a decrease in neuroticism, and a marked decrease in psychoticism.

5. The main EEG findings after cingulectomy are given. Chronic epilepsy is often improved by the operation.

6. The main physiological interest of anterior cingulectomy seems to be the now well-substantiated suggestion of a difference in function between dorsal granular cortex (areas 9 and 10) and mesial agranular cortex (area 24).

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RHINORRHEA AND PNEUMOCEPHALUS

SURGICAL TREATMENT

HUGO V. RIZZOLI, M.D.,* LT. COL. GEORGE J. HAYES, M.C., U.S.A.,† AND HARRY F. STEELMAN, M.D.†

Washington, D.C.

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CEREBROSPINAL fluid rhinorrhea, or the discharge of cerebrospinal fluid from the nose, has beeen known for many years. Neurosurgeons and their otolaryngological colleagues have been aware of the potential dangers of rhinorrhea. Cerebrospinal fluid fistula may result in a meningitis or brain abscess. Though the mortality from these infections in recent years has been reduced by the administration of the antibiotics, there remains a significant risk. When rhinorrhea is present there must be a communication with the subarachnoid space or with one of the cerebral ventricles.

Rhinorrhea can result from (1) fractures of the skull in the vicinity of the paranasal sinuses, (2) postoperative defects, (3) erosions caused by tumors or infection, and (4) congenital anomalies. Spontaneous closure of these fistulae may occur. There are reported cases in which fistulae have persisted for years. Thomson[15] reported the occurrence of rhinorrhea in a patient in whom it had persisted for several years. Plum[13] described a case of fistula of 18 years' duration. Many more fatal cases have been reported. Most all neurosurgeons now agree that chronic rhinorrhea requires surgical intervention. Grant[11] attempted to close a cerebrospinal fluid fistula by an intracranial exposure. Dandy[7] reported the first successful attempt to close such a fistula with fascia lata graft. Cushing[6] reported the successful surgical treatment with fascial grafts in 3 patients in whom rhinorrhea developed following the removal of orbito-ethmoidal osteomas. Several others have reported patients cured by surgery: Rand,[14] Cairns,[3] Gissane and Rank,[10] Adson,[1] Campbell, Howard, and Weary,[4] German,[9] Dandy,[8] and Adson and Uihlein.[2]

Pneumocephalus, or air within the cranial cavity, is sometimes seen in a patient with a cerebrospinal fluid fistula. Extracranial and subgaleal collections of air arising from a communication through the outer wall of a cranial air sinus have been recognized for a century and a half, according to Dandy. Intracranial collections of air, however, had gone unrecognized until the advent of the x-ray, with the exception of the famous case reported by Chiari[5] in 1884. At autopsy, he found air in a large cavity in the frontal lobe and in the ventricular system, and he found communication from an ethmoid

* George Washington University School of Medicine, Washington, D. C.
† Formerly Neurosurgical Section, Walter Reed Army Hospital, Washington, D. C.

sinus to the frontal fossa secondary to an infection. He explained the presence of the intracranial air as having been caused by the explosive force of sneezing. Luckett,[12] in 1913, reported the first case of pneumocephalus visualized by x-ray. Dandy[7] reviewed 25 cases which he found in the literature and added 3 of his own, in 1 of which he cured the patient by intracranial surgery. He stated: "There are two sources of intracranial air: (1) a break in the wall of the skull, through which air is forced from the exterior, and (2) the product of gas producing organisms after their entrance into the brain. After the initial cranial defect, air can be forced into the brain only through an opening in one of the paranasal sinuses or the mastoid cells, for here alone can the air be concentrated by swallowing, coughing or sneezing under a pressure greater than that within the cranial chamber." He indicated that the intracranial air can be located in (1) the subarachnoid space, (2) the subdural space, (3) the brain, and (4) the ventricles. Dandy felt that subarachnoid air must gain entrance through the cisternae at the base of the brain via the ethmoid or sphenoid sinus. Subdural air could occur from a communication with a frontal sinus. He found that the intracerebral cavity was most common and that with this cavity there is always a communication with a frontal or ethmoid sinus. Intraventricular pneumocephalus usually occurs secondary to intracerebral or subarachnoid collection of air. It seems likely that there must be some valve-like action in the fistulous opening. Dandy discussed this point at length and he stressed the danger of sneezing in the presence of rhinorrhea.

MATERIAL

In this report we are presenting 15 cases of chronic rhinorrhea and 12 cases of persistent pneumocephalus. All but one of these 27 patients were treated surgically during a 7-year period ending 1 year ago and cured of the rhinorrhea and pneumocephalus. Case 9 was not treated. The patient elected to return to Brazil to the surgeon who had originally operated on him for a suprasellar cyst.

Rhinorrhea (Table 1). Of the 15 cases, trauma was the etiological agent in 13, congenital nasal meningocele in 1, and postoperative craniotomy for suprasellar cyst in 1. In the traumatic group, 9 were cases of frontal fractures following auto or jeep accidents, and 4 were caused by shell or gunshot wounds, one of which was self-inflicted. At the time of surgery, the duration of rhinorrhea varied from 1 month to 5 years. Only 3 of these patients were known to have had meningitis (Cases 2, 10 and 15). Case 2 had had four attacks of meningitis.

At surgery, an opening communicating with the ethmoid sinus was found in 10 cases, and in 3 the opening communicated with the frontal sinus. In Case 12, there was a communication with both the right frontal and left ethmoid sinuses. The second fistula was not discovered until the second operation. Cases 5 and 13 required three surgical attacks before closure of the cerebrospinal fluid fistula was accomplished. Case 15 had to be operated up-

TABLE 1

Rhinorrhea (15 cases)

Case	Age	Etiology	Time Elapsed*	Symptoms and Signs	Duration of Rhinorrhea†	Sinus Involved	Result after Surgery	Remarks
1. D.D.	17	Jeep accident	1 mo.	Headache, rhino., blind lt. eye	2 mos.	Rt. eth.	Cured	Persistent blindness on lt.
2. C.P.	36	Auto accident	4 yrs.	4 attacks meningitis, intermit. rhino.	4 yrs. intermit.	Lt. eth.	Cured	No rhino. at time of op
3. G.V.	26	Auto accident	10 wks.	Intermit. rhino.	22 wks.	Lt. eth.	Cured	
4. N.B.	7	Nasal meningocele	5 yrs.	Headache, intermit. rhino.	5 yrs.	Rt. eth.	Cured	Rhino. started after a fall. Meningocele in nasal cavity
5. T.C.	29	Auto accident	2 mos.	Intermit. rhino.	a. 2 mos. b. 3 mos. c. 4 mos.	Rt. eth.	Well after 3 ops.	
6. G.H.	20	Auto accident	4 hrs.	Depressed fracture, onset rhino. 2 mos. after injury	1 mo.	Lt. eth.	Cured	
7. R.D.	20	Auto accident	10 hrs.	Headache, rhino.	6 wks.	Lt. eth.	Cured	Chronic scalp sinus from foreign body. Bone flap had to be removed
8. W.H.	24	Shell fragment	4 wks.	Onset rhino. 1 yr. after injury	1 mo.	Rt. fr.	Cured	
9. F.H.	21	Shell fragment	1 mo.	Rhino., rt. eye enucleated	7 wks.	Bilat. fr.	Cured	Epidural abscess drained at time of op.
10. A.M.	41	Postop.	6 yrs.	Intermit. rhino., meningitis			No op.	Pt. returned to Brazil for treatment. Had had suprasellar cyst removed
11. W.B.	21	Auto accident	4 wks.	Persistent rhino.	5 wks.	Eth.	Cured	Pt. had previous op. for depressed bifrontal fracture
12. C.L.	21	Auto accident	9 mos.	Intermit. rhino., deaf, marked loss vision	a. 10 mos. b. 11 mos.	a. Rt. fr. b. Lt. eth.	a. Not cured b. Cured	Deaf and loss of central vision only on lt.
13. H.B.	39	Gun shot	5 mos.	Persistent rhino.	7 mos.	Lt. eth.	3 ops. Cured	Self-inflicted wound
14. J.K.	23	Shell fragment	2 mos.	Aphasia, rt. hemiplegia, rhino.	5 mos.	Lt. fr.	Cured	Initial debridement overseas, practically lt. hemispherectomy
15. P.P.	23	Auto accident	5 yrs.	Intermit. rhino., 1 yr. after injury, recurrent meningitis, headache	a. 4 yrs. intermit. b. 4 yrs. 2 mos.	Lt. eth.	a. Not cured b. Cured	Auto accident 5 yrs. before. Aseptic meningitis 1 wk. after 1st op. No CSF leak after 2nd op.

* Time elapsed when seen by us.
† Duration of rhinorrhea at time of surgery.

on twice before cure was effected. In Case 7 a wound infection developed, and the bone flap had to be removed because of osteomyelitis; the wound did not heal until a foreign body was removed. Case 10 was not operated upon.

Pneumocephalus (Table 2). Of the 12 cases, 10 were of traumatic origin, 1 (Case 21) occurred following removal of a sphenoid ridge meningioma and 1 (Case 17) was secondary to an osteoma of the frontal sinus. In the trau-

matic group, 6 sustained frontal fractures in auto accidents. Three cases resulted from gunshot wounds: 2 self-inflicted, and 1 accidentally incurred. Case 24 had a compound depressed frontal fracture caused by an industrial accident.

Intracranial air was first discovered from 1 week to 2 years after injury in the traumatic cases. Pneumocephalus was first detected in Case 17 (osteoma of frontal sinus) $1\frac{1}{2}$ months after the onset of symptoms. In Case 21, in which a sphenoid ridge meningioma had been removed, pneumocephalus was first detected 2 months after surgery. Many of these patients were confused and disoriented when seen by us. Headache was a common complaint. Three of these patients were known to have had an episode of meningitis before

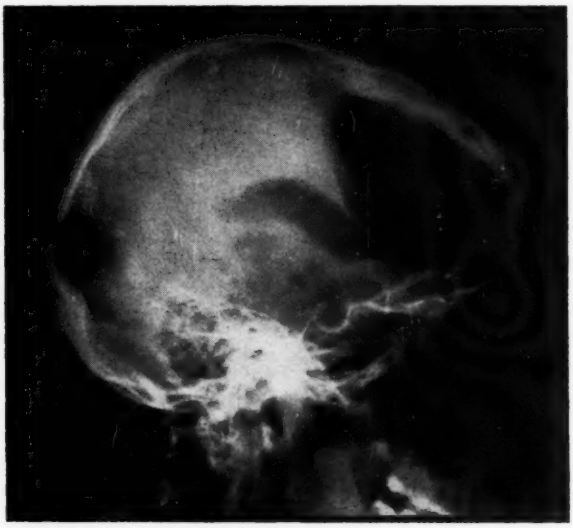

FIG. 1. *Case 18* (Table 2). Pneumocephalus and pneumoventricle secondary to self-inflicted gunshot wound.

surgery. A history of cerebrospinal fluid fistula (usually rhinorrhea) was obtained in all cases but one. Five of the 12 patients were known to have convulsions, whereas while under our care none of those in the rhinorrhea group was known to have convulsions. A communication with an ethmoid or a frontal sinus was found in all cases excepting Case 23. In this case, there was a cerebrospinal fluid fistula in the craniectomy wound in the left frontal region through which debridement of skull, dura mater, and brain had been accomplished elsewhere. At surgery, it was determined that this fistula was the site of entrance of the air; the dura mater had not been closed. The location of the air in these cases of pneumocephalus was most commonly within the substance of the frontal lobe. A pneumatocele was found in the frontal lobe in 10 cases. In 6 of these cases, there was also pneumoventricle. In 1 of

TABLE 2

Pneumocephalus (12 cases)

Case	Age	Etiology	Time Air Was First Detected*	Symptoms and Signs	Time Elapsed Before Surgery*	Sinus Involved	Location of Air	Result of Surgery	Remarks
16. K.H.	25	Auto accident	3 mos.	Rhino., headache, confusion, meningitis	a. 4 mos. b. 5½ mos.	a. Rt. fr. b. Rt. eth.	Brain ventricle subdural	a. Not cured b. Cured	Rhino. persisted until 2nd op. Convulsions
17. J.L.	21	Osteoma lt. fr. sinus	1½ mos. after symptoms	Headache, rt. hemiparesis, meningitis, convulsion, history of rhino.	2½ mos.	Lt. fr.	Brain ventricle subdural	Cured	Air aspirated at previous hospital, through burr hole
18. M.P.	22	Gun shot	1 mo.	Rhino., confusion, fever	2¾ mos.	Lt. fr. Lt. eth	Brain ventricle (Fig. 1)	Cured	Self-inflicted
19. R.C.	34	Auto accident	3 wks.	Rhino., headache	4 mos.	Rt. eth.	Subdural	Cured	Rt. 3rd nerve since injury
20. E.B.	33	Gun shot	1 mo.	Rhino., rt. hemiparesis	1½ mos.	Lt. fr.	Brain ventricle	Cured	Bullet wound, convulsions
21. B.W.	45	Postop.	2 mos.	Headache, rhino.	2¼ mos.	Rt. eth.	Brain ventricle	Cured	Meningioma had been removed from sphenoid ridge
22. C.P.	21	Auto accident	2½ mos.	Drowsiness, diabetes insip., rhino., bitemp. hemianopsia	3 mos.	Rt. eth.	Subarachnoid ventricle	Cured	
23. C.J.	57	Gun shot	1 mo.	Confused, CSF fistula in wound, lethargy, vomiting	1¾ mos.	None—fistula communicated with lt. fr. wound	Brain	Cured	Bullet wound self-inflicted, convulsions
24. O.W.	42	Depressed fracture at work	2 mos.	Disoriented, headache. Rhino. at time of injury	2½ mos.	Lt. eth.	Brain	Cured	Sneezing followed by sudden headache day before pneumo. discovered
25. J.M.	18	Jeep accident	3 wks.	Meningitis, rhino., bitemp. hemianopsia	2 mos.	Rt. fr.	Brain ventricle	Cured	Postop. extradural hemorrhage
26. W.B.	20	Auto accident	1 wk.	Blind, rhino., headache	3 wks.	Rt. eth.	Brain	Cured	Blindness from direct injury to eyes
27. H.S.	30	Jeep accident	2 yrs.	Convulsion 2 yrs. after injury, confused, rt. facial	2 yrs.	Lt. fr.	Brain	Cured	

* Time elapsed since trauma or other etiological cause.

these cases, there was also subdural air. There was only 1 other case of subdural location of air. In Case 22, there was pneumoventricle and subarachnoid air. All but 1 of the patients with pneumocephalus were cured by one operation; in Case 16 a second operation was necessary to cure persistent rhinorrhea.

Either a bilateral coronal scalp incision or unilateral concealed frontal incision was made under general anesthesia. Unilateral frontal bone flap on the same side as the rhinorrhea was made in most cases. In 2 cases, the ex-

posure was accomplished through a previously existing frontal craniectomy defect. The exact surgical technique varied somewhat from case to case. When present, intracerebral aerocele was evacuated as soon as the exposure was made. Usually extradural exploration was done first, with exposure of the posterior table of the frontal sinus and the cribriform plate. The bony defect was usually filled with muscle, cauterized in place, and covered with gel foam. If the rent in the dura mater could be closed from this approach, this was done usually with fine silk sutures. It was usually necessary to use a fascial graft. Temporal fascia, galea, or pericranium were used. Most often, the defect in the dura mater was attacked intradurally and extradurally. When it was not feasible to suture the graft in place in a water-tight fashion, the graft was placed over the bone defect, tacking it in place with occasional sutures, often to the falx.

Comments. All 27 patients received antibiotic medication; in the earlier cases penicillin and sulfadiazine were given; the drugs were administered for a few days before surgery as well as postoperatively. The surgery usually was done under inhalation anesthesia and with tracheal intubation. Concentrated human albumin intravenously was used in occasional cases to shrink the brain for better exposure, especially in those cases of rhinorrhea without pneumocephalus. Twenty-six of the 27 patients were operated upon without mortality and without increasing the pre-existing neurological deficit. The remaining patient was not operated upon by us. Of these 26 patients, 21 were cured by one operation, 3 required two operations and 2 required three operations.*

DISCUSSION

With intracerebral pneumatocele, it seems logical to expect a laceration of the brain and pia arachnoid in the vicinity of the dural fistula. This has been true in all our cases. Rhinorrhea may subside when the pia arachnoid, brain, and dura mater become adherent about the fistulous tract. However, if the pneumatocele later communicates with a ventricle, profuse rhinorrhea can occur. Intracranial air can produce symptoms because of (1) the increased intracranial pressure, (2) irritating effect of the air, and (3) infection, acute or chronic.

Patients with pneumocephalus usually show some degree of confusion and are usually quite ill. When pneumoventricle and rhinorrhea are absent the intracranial pressure tends to be greater. Convulsions are often seen and in Case 17 hemiparesis could definitely be attributed to a pneumatocele.

Spontaneous closure of the fistula is known to have resulted in the cure of pneumocephalus and rhinorrhea. This is more likely to happen in cases in which intracranial pneumocephalus occurs immediately after injury and not when it is of delayed onset. There may be late recurrences of rhinorrhea with meningitis in cases of apparent spontaneous cure. We feel that surgery is in-

* The third operation in Case 13 was done successfully by Col. John Martin.

dicated when rhinorrhea or pneumocephalus has existed for 3 or 4 weeks. The surgical risk is not great.

Water-tight closure of the dural defect is most successful though not always possible. Overlooking a second fistula will almost surely result in failure to effect a cure. It is possible that in an occasional patient who is apparently cured, recurrence of rhinorrhea can develop in the future.

SUMMARY

Fifteen cases of chronic rhinorrhea and 12 cases of persistent pneumocephalus are presented. Twenty-six of these patients were operated upon. Successful obliteration of the fistulous tract was accomplished in all surgical cases, without mortality or added neurological deficit. Five patients required multiple attacks before cure was effected.

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PERITONEAL SHUNT FOR HYDROCEPHALUS

UTILIZING THE FIMBRIA OF THE FALLOPIAN TUBE FOR ENTRANCE TO THE PERITONEAL CAVITY*

GRIFFITH R. HARSH, III, M.D.

Department of Surgery (Division of Neurological Surgery), Washington University School of Medicine, St. Louis, Missouri

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THOUGH recognized by the ancients, hydrocephalus, as noted by Dorothy Russell,[19] remained an anatomical enigma until the time of Vesalius[20] who gave the first accurate description of an autopsied case. It remains a partial etiological enigma until the present time. However, a great deal of knowledge has accumulated concerning its origin through the efforts of numerous workers from Magendie through Dandy. The saga of the treatment of hydrocephalus has been well documented in numerous reviews.[1,4,8,12] On the whole, treatment has been directed toward either reducing the quantity of cerebrospinal fluid or shunting cerebrospinal fluid into areas where absorption or excretion may occur. Many ingenious shunting procedures have been devised.

Ureterothecal Anastomosis. Shunting fluid from the subarachnoid space into the ureter after nephrectomy was first proposed and attempted by Drachter[5] and independently by Heile[10] in 1925. Heile anastomosed the kidney pelvis directly to the subarachnoid space. This procedure was modified by Matson[14] who utilized a polyethylene catheter inserted into the subarachnoid space and into the free end of a ureter detached from the renal pelvis. Matson's method has had rather wide acceptance and has been effective in many instances.[15] There are, however, as pointed out by Matson, certain disadvantages which warrant further search for a means of diverting the cerebrospinal fluid of a communicating hydrocephalus. These include: (1) sacrifice of a kidney, (2) loss of fluid and electrolytes resulting from excretion of the cerebrospinal fluid with the urine and (3) possible retrograde infection.

Ventriculomastoid Shunts. In 1950 Nosik[17] proposed ventriculomastoid shunts employing a cannula connecting the dilated temporal horn of the lateral ventricle with the antrum of the mastoid. Because of the high incidence of middle ear infection in childhood and the attendant danger of meningitis, this ingenious method carries a significant risk.

Peritoneal Shunts. Cerebrospinal fluid diversion to the peritoneum was first attempted by Ferguson[6] in 1898. He accomplished this with a U-shaped silver wire passed from the subarachnoid space about the cauda equina

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through a drill hole in the 5th lumbar vertebra into the peritoneum. In 2 cases reported, the first patient died shortly, and the second after 3 months' improvement. In 1905 Nicoll[16] attempted a peritoneal shunt by attaching omentum, which was brought through a paravertebral opening, to a defect in the spinal dura mater. Ventriculoperitoneal shunt was attempted with a rubber tube by Kausch[13] in 1905 and with a silver wire by Hartwell[7] in 1910. The latter's patient is particularly interesting in that he survived for 2 years. After death from a brain stem tumor without evidence of increased pressure, a patent scarred tube was found connecting the ventricle and the peritoneum. Cushing[2,3] accomplished peritoneal shunts in 1905 by means of a silver cannula passed through the 4th lumbar vertebra into the peritoneal cavity. Twelve patients were treated in this way, but the operation was abandoned because of the development of intussusception and death in 2 patients. Cushing attributed these complications to the presence of pituitary secretion in the cerebrospinal fluid causing increased peristalsis. Further attempts at a peritoneal shunt were made by Heile[9] by means of silk threads, vein grafts, and a rubber tube from the dura mater to the peritoneum.

Following these early trials with peritoneal shunts the procedure fell into disrepute among modern surgeons. It has recently been revived by Cone, Lewis, and Jackson[12] who advocate ventriculoperitoneal and in some instances lumbar subarachnoid-peritoneal shunts. Analysis of their results has not yet been published. The experience of others seems to indicate frequent failure of the peritoneal shunts because of obliteration of the peritoneal end of the shunting tube by exudate or adhesions.[1]

Other Shunting Procedures. Among other methods that have been suggested are shunts from the ventricles to the pleural cavity and to major venous sinuses. Experimental pleural shunts were found unsatisfactory by Ingraham and co-workers.[11] This has also been our experience in patients. Attempts to sidetrack the cerebrospinal fluid into large venous channels have been made unsuccessfully since proposed by Payr[18] in 1908 and Haynes[8] in 1913.

Ideally a shunt will provide for removal of excess cerebrospinal fluid from its usual habitat and for its reabsorption to prevent fluid and electrolyte imbalance. Persistent patency in the presence of normal cerebrospinal fluid pressure, minimal local reaction to the shunting mechanism and least opportunity for central nervous system infection are imperative. It is the purpose of this communication to propose a workable modification of the peritoneal shunt applicable to female hydrocephalics and to present the early results in 12 patients so treated.

METHOD

Preliminary Considerations. Demonstration of hydrocephalus and determination of its type is effected by combined ventricular and lumbar puncture. If PSP or indigo carmine dye placed in the ventricle appears in the lumbar cistern within 30 minutes, adequate communication is considered present. Air studies have been useful in excluding the presence of a tumor as

well as helpful in further determination of patency of the aqueduct of Sylvius. In patients whose hydrocephalus is secondary to meningitis inactivity of infection has been established by the following criteria: (1) absence of bacteria by culture, (2) normal temperature, (3) normal cerebrospinal fluid cytology, and (4) a rising spinal fluid sugar level of 35 mg. per cent or more. These rather arbitrary criteria have seemed satisfactory.

Operative Technique. With the patient in the right lateral recumbent position, laparotomy is performed through a McBurney muscle-splitting incision. The intestines are packed superiorly out of the operative field with moist sponges and the fallopian tube with its associated ovary is isolated. A heavy silk suture is placed through the mesosalpinx, around the fallopian tube, and the tube is ligated about 2-3 cm. proximal to the fimbria (Fig. 1). The mesosalpinx is left intact. A small rounded metal probe is then inserted into the fimbria and passed through the lumen of the

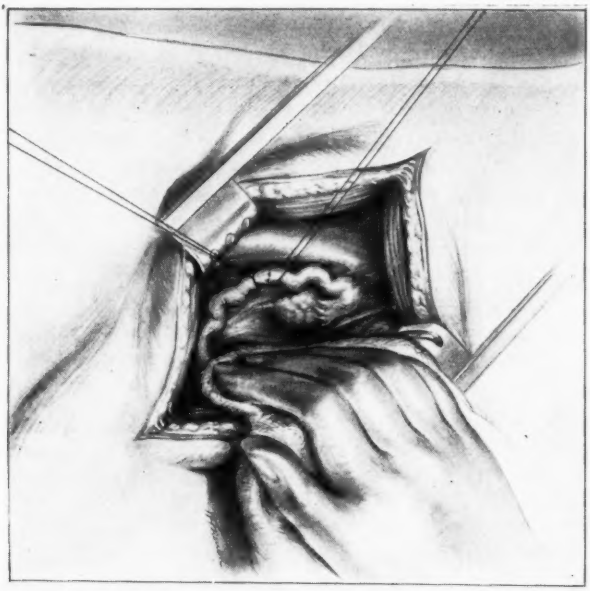

FIG. 1. Showing exposure of fallopian tube and ovary through a McBurney incision. Ligatures are placed on either side of point of incision (dotted line) into fallopian tube.

salpinx in a retrograde fashion to the level of the previously placed ligature. An incision is made through the wall of the salpinx and the probe is passed free into the peritoneal cavity. A curved #18 polyethylene tube, preformed in hot water, is threaded over the probe which is retracted into the lumen of the salpinx, detached from the polyethylene tube and withdrawn. The polyethylene catheter is then secured with two sutures transfixing the lumen of both it and the salpinx, and a purse-string suture in the wall of the salpinx (Fig. 2).

Through a separate midline lumbar incision a partial right hemilaminectomy of

the 2nd or 3rd lumbar vertebra is performed. A Kelly clamp is passed through the paraspinal muscles to the retroperitoneal space, and under direct vision the posterior peritoneum is incised over the end of the clamp. The previously fixed polyethylene catheter is brought through this tunnel to present in the laminectomy wound (Fig. 3). The dura mater and arachnoid are opened between two stay sutures and the free perforated end of the polyethylene catheter is inserted caudally into the subarach-

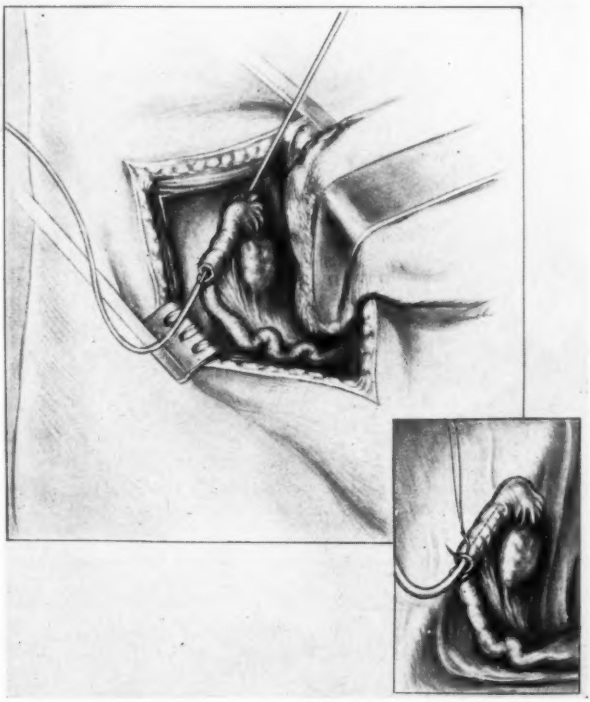

FIG. 2. Probe introduced through fimbria as guide for polyethylene tube to be inserted into salpinx. (*Inset*) Tube being anchored by suture.

noid space. Care is taken to ascertain that the tube is placed beneath the arachnoid and not merely subdurally. The dura mater is closed in routine fashion and the tube is secured with a single fine silk suture transfixing its lumen (Fig. 4). The intra-abdominal loop of the catheter is then fixed to the parietal peritoneum deep in the iliac fossa with a single silk suture. Routine closure of the wounds is then completed.

In certain instances (e.g. lumbar arachnoiditis, myelomeningocele, cisterna magna obstruction) it may be desirable to create a shunt directly from the cerebral ventricles to the salpinx. In these, telescoped tubes are passed through the paravertebral musculature, up the subcutaneous tissues of the back and through an occipitoparietal perforator opening into the ventricle (Fig. 5). It is felt that the use of a telescoped tube for the ventriculosalpingeal anastomosis may be of value to counteract discrepancies in body and tube length as the patient grows.

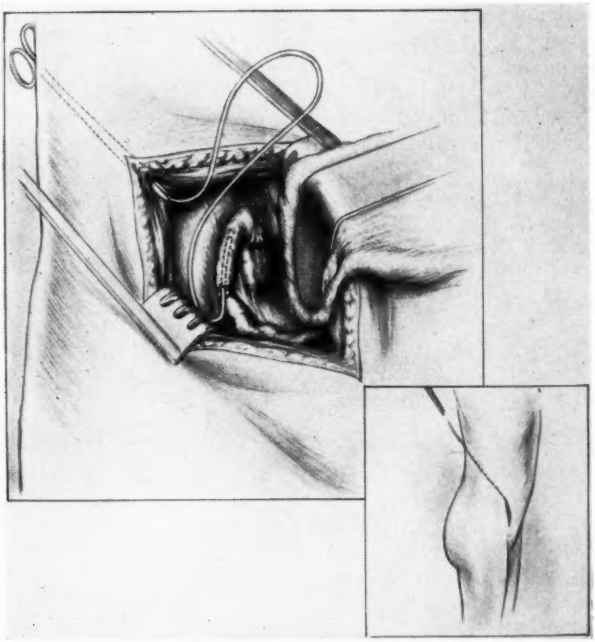

FIG. 3. Proximal end of polyethylene tube is pulled through paraspinal muscles for subsequent implantation into lumbar subarachnoid space.

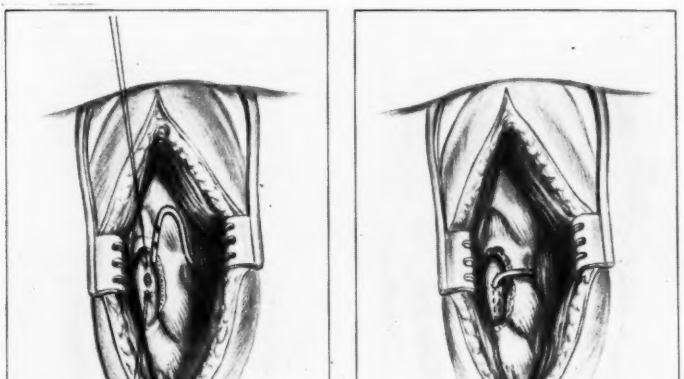

FIG. 4. Through a partial hemilaminectomy the tube is inserted into lumbar theca and anchored by a transfixion suture to the dura mater.

Postoperative Considerations. Following operation oral feeding is withheld for 24 hours to decrease the incidence of postoperative distention. Immediately after surgery there is depression of the fontanelle and some over-riding of sutures as a result of cerebrospinal fluid loss at operation. During the sec-

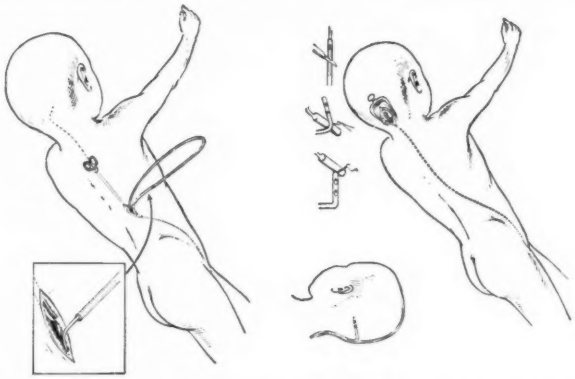

FIG. 5. (*Left*) For ventriculosalpingostomy, after fixing the distal end of the catheter in salpinx, the proximal end is carried subcutaneously up to the occipital area. Tubing is telescoped in anticipation of body growth. (*Right*) Rostral end of tube inserted into lateral ventricle through a burr hole. (*Insets*) Details of making lateral openings into tube and bending and sealing it over a small heating iron.

ond and third 24-hour periods the fontanelle again becomes tense, presumably because of spasm of the salpinx secondary to operative manipulation. By the fourth day, the fontanelle gradually becomes soft and concave.

RESULTS

This method has been employed in 12 unselected patients. Salpingothecal anastomosis was performed in 8 instances and ventriculosalpingostomy in 4. Among the 12 patients there have been 2 deaths. The first patient had a salpingothecal anastomosis and death occurred 24 hours following cardiac arrest on the operating table. The second patient had had a ventriculosalpingostomy and died 2 months postoperatively. Her father reported that she had been active the day before her death and more alert than at any time prior to operation. Death was sudden without apparent increase in pressure and with no evidence of infection. Autopsy was not obtained. Of the 7 living patients with salpingothecal shunts, all are apparently functioning at the present time. Of the 3 living patients with ventriculosalpingostomies, 2 are apparently functioning; 1 is not. In evaluating the results of the operations, criteria for a functioning shunt have included: (1) retraction of the previously bulging fontanelle, (2) collapse and over-riding of the previously separated sutures and (3) cessation of disproportionate head enlargement (with actual shrinkage in the younger children).

Five of the patients in this series required two or more operative procedures because of initial failure. Subsequent reoperation on these has revealed

the following causes of failure: (a) Mechanical failure of the shunt caused by displacement of the polyethylene tube from the lumbar cistern. This has occurred in 4 patients. In the first the catheter had been placed extraperitoneally and the displacement was felt to have been incident to postoperative abdominal distention. Catheters are now placed transperitoneally and fixed to the dura mater with a suture transfixing the lumen of the tube. (b) Kinking of the tube at the site of the lumbar cisternal insertion. This can be avoided by preforming the tube with heat before placing it in the subarachnoid space (c) Arachnoiditis obliterating the lumbar cistern occurred in 1 patient (G.M.). The polyethylene tube was subsequently removed and placed in the ventricle. In one other instance in which the tube had slipped from the subarachnoid space, moderate arachnoiditis was noted at re-exploration. Reinsertion of a new tube into the lumbar theca has apparently proved effective. (d) Peritoneal adhesions about the fimbria were responsible for failure to function in only 1 patient (M.K.). In this infant initial salpingothecal anastomosis was found to be nonfunctioning after 2 months. A second operation revealed that the tube had slipped out of the lumbar cistern and re-anastomosis was performed using a new tube. The second procedure also failed. Re-exploration showed the presence of a constricting band and a large thin-walled cyst about the fimbria. Freeing the fibrous band and evacuation of the cyst resulted in a functioning shunt. It is of course obvious that the incidence and severity of adhesions increases with successive operations.

In this series of patients there has been no evidence of fluid or electrolyte imbalance; nor has there been evidence of meningitis or other central nervous system infection. Postoperative abdominal distention has been transitory and has responded to conservative management. There have been no untoward effects from reduction of cerebrospinal fluid pressure. Decompression has usually been slowly progressive except for that immediately incident to fluid loss during the insertion of the catheter into the ventricle or subarachnoid space.

All of the patients have had a communicating type of hydrocephalus except 3. Two of these infants had a noncommunicating hydrocephalus which had been treated with a tube running from the lateral ventricle to the cisterna magna. Following the Torkildsen procedure hydrocephalus progressed although communication between the ventricles and the lumbar cistern was subsequently demonstrated. In each a salpingothecal anastomosis was performed, leaving the Torkildsen tube in place. In one of these subsequent arachnoiditis led to failure to function. A ventriculosalpingostomy was then performed.

In 9 patients there was no demonstrable cause for congenital hydrocephalus. Two patients had hydrocephalus associated with myelomeningocele. In 1 infant hydrocephalus developed after meningitis.

The patients in this series were between 3 months and 3 years of age at the time of operation. The longest postoperative interval is 12 months; the shortest, 8 weeks (Table 1). The postmeningitic patient has been followed

TABLE 1

Case	Age (mos.)	Type	Operation	Remarks	Result
E.S.	3	Communicating	Salpingothecal (2)	First tube slipped out of theca; replaced.	Functioning shunt, 12 mos. follow-up.
R.B.	5½	Mixed	Torkildsen Salpingothecal	Aqueductal stenosis and obliterated lateral cisterns.	Functioning, 10 mos. after salpingothecal.
R.G.	11	Communicating	Salpingothecal	Shunt above associated myelomeningocele.	Functioning, 9 mos. after shunt.
B.J.	3	Communicating	Salpingothecal	Cardiac arrest at operation, temporary response to cardiac massage.	Died, 24 hrs.
M.R.	6	Communicating	Salpingothecal	Postmeningitic hydrocephalus	Functioning, 6 mos. follow-up.
C.P.	4½	Communicating	Salpingothecal (2) Ventriculosalpingostomy	First tube slipped, replaced; inadequate communication from kinking (?)	Functioning, 5 mos. after ventriculosalpingostomy
C.K.	12	Communicating	Ventriculopleural Ventriculosalpingostomy	Associated myelomeningocele. Pleural shunt ineffective.	Functioning, 6 mos. after ventriculosalpingostomy.
C.C.	7	Communicating	Salpingothecal		Functioning, 5 mos. follow-up.
M.K.	7	Communicating	Salpingothecal (2) Exploratory laparotomy	First tube slipped out of lumbar cistern; replaced. Subsequent laparotomy showed cyst around fimbria, plus adhesion across fimbria.	Functioning, 3 mos. after freeing perifimbrial cyst.
A.B.	7	Communicating	Salpingothecal (2)	First tube slipped out of lumbar theca; replaced.	Functioning, 3 mos. follow-up.
J.P.	36	Non-communicating	Ventriculosalpingostomy	Rapid progression of previously considered "arrested hydrocephalus." Shunt apparently successful for 2 mos.; died suddenly at home, exact cause unknown.	Died, 2 mos. after functioning shunt.
G.M.	3	Mixed	Torkildsen Salpingothecal Ventriculosalpingostomy	Associated tracheoesophageal fistula successfully repaired. Arachnoidal adhesion following salpingothecal.	Nonfunctioning, 2 mos.

for 6 months without evidence of failure of the shunt or of recurrence of meningitis.

ILLUSTRATIVE CASE REPORT

R.B., a 3-month-old white female infant, was first admitted to the St. Louis

Children's Hospital on Oct. 1, 1952, with a history of enlargement of the head for 2 to 3 weeks.

Examination revealed an obviously hydrocephalic head with a circumference of 47.2 cm. The fontanelle was tense and bulging, the sutures were separated and the veins of the scalp were prominent. Reflexes were hyperactive and muscle tone was increased in all extremities. X-ray films of the skull revealed separation of the cranial sutures. Combined ventricular and lumbar punctures revealed no communication. Ventriculograms showed markedly dilated lateral ventricles. A diagnosis of aqueductal stenosis was made.

1st Operation. Ventriculocisternostomy (Torkildsen procedure) was done.

Course. There was immediate collapse of the fontanelle and over-riding of the sutures. After 1 week the head began to re-expand. The patient was discharged 2 weeks after operation to be followed in the Washington University Clinics. As the head continued to enlarge she was readmitted to St. Louis Children's Hospital on Nov. 8, 1952.

2nd Operation. Combined puncture demonstrated communication between the lateral ventricles and the lumbar cistern. Re-exploration of the suboccipital region confirmed patency of the Torkildsen tube with free communication between the lateral ventricle and the cisterna magna. It was noted that the lateral cisterns were obliterated and it was assumed that this factor was responsible for failure of reabsorption of cerebrospinal fluid.

Course. Enlargement of the head progressed to 49 cm. in circumference. The anterior fontanelle was large, tight and bulging and the cranial sutures were separated.

3rd Operation. On Dec. 24, 1952, a salpingothecal anastomosis was performed.

Course. The fontanelle remained full but soft for 2 days, and then progressively receded. The patient was discharged 8 days after operation in good condition.

Since discharge she has been followed regularly, and was last seen on Oct. 26, 1953, 10 months after salpingothecal anastomosis. There has been steady mental and social development. She is now 16 months old—walks without assistance, chatters incessantly, and has a small vocabulary compatible with her age. The head measures 48 cm. (O.F. circumference), the chest 48 cm. The fontanelle is concave, firm and closing. She is apparently bright and of normal intelligence. There has been no gastrointestinal disturbance, and no evidence of fluid accumulation in the abdomen.

DISCUSSION

Davidoff[4] stated "the difficulty . . . with the operations [i.e. shunting procedures] though logically conceived in relation to the mechanism of the liquor circulation, is that they often fail to take into consideration the reaction on the part of the body toward the newly established pathways and toward the material utilized in establishing these pathways." It is believed that the operation herein proposed overcomes at least part of these difficulties. It has long been felt that the reason for failure of cerebrospinal-peritoneal shunts has been the ability of the peritoneum and its omentum to form protective adhesive coatings about foreign bodies and other irritants. It is therefore apparent that a "physiological" access to the peritoneum for cerebrospinal fluid is most desirable. Such an entrance is apparently afforded by the fimbria of a ligated fallopian tube. Since the end of the polyethylene

catheter is enclosed within the salpinx, peritoneal or omental reaction to the catheter itself would not be expected to be of significance.

Jackson[12] pointed out that arachnoidal reaction to a polyethylene catheter among the roots of the cauda equina may occur. In the present group of cases, this proved to be responsible for failure in only 1 patient and was overcome by performing a ventricular shunt.

As shown by Matson[15] the main disadvantage of shunting procedures that allow for escape of cerebrospinal fluid outside the body is fluid and electrolyte imbalance. Reabsorption of cerebrospinal fluid from the peritoneum precludes this possibility.

The pitfalls of early optimism for therapeutic procedures for hydrocephalus are manifold. Final evaluation of the efficacy of the proposed procedure must come only after much wider trial and more prolonged follow-up. There are many areas of possible concern for the future. Growth discrepancy is perhaps primary. Although little disproportion between body growth and tube distance is anticipated in the salpingothecal anastomoses, this looms as an important factor in ventriculosalpingeal shunts. It is hoped that the telescoped polyethylene tube, with its potential for insertion of an additional length of tubing, will be effective over the period of normal growth.

Other sources for concern include: (1) the possibility of back pain from lumbar arachnoiditis, (2) the sequelae of pregnancy with its enlarged uterus and possible compression of the polyethylene and fallopian tubes.

The ultimate test of the efficacy of any therapeutic procedure must depend upon the patient's subsequent intellectual and social development. The follow-up of these patients has been too short to warrant definite conclusions. Furthermore, in the earlier cases at least, no attempt has been made to select patients with early or mild degrees of hydrocephalus. Despite this it seems apparent that all but one of the patients with successfully arrested hydrocephalus have progressed favorably and that at least some give promise of adequate behavior and intelligence.

SUMMARY

1. Modern surgical procedures for treating hydrocephalus have been briefly reviewed.

2. A modified method of cerebrospinal fluid-peritoneal shunt, utilizing the fimbria of the fallopian tube for entrance into the peritoneal cavity, is described.

3. An analysis of the results in 12 patients so treated and a representative case summary are presented.

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ADDENDUM

One month after preparation of this manuscript, the nonfunctioning ventriculosalpingostomy (G.M. Table 1) was revised; the tube was found to be obstructed at ventricular end and had retracted out of the fallopian tube; a new tube was inserted with subsequent restoration of function. At time of proofreading, an additional 4-month follow-up shows that all shunts are functioning satisfactorily except for the doubtful status of C.P., whose head circumference after primary decrease has returned to pre-operative dimensions, although the fontanelle has decreased in size and is concave.

VENTRICULO-PLEURAL ANASTOMOSIS

IN TREATMENT OF MIDLINE OBSTRUCTIONAL NEOPLASMS

JOSEPH RANSOHOFF, M.D.

Department of Neurological Surgery, Neurological Institute, Presbyterian Hospital of New York, and Columbia University, New York, New York

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THE accepted approach to the treatment of posterior third ventricle tumors, obstructive brain stem gliomas and certain inoperable posterior fossa neoplasms has been a combination of operative therapy planned to relieve the secondary hydrocephalus followed by x-ray therapy directed towards the underlying neoplasm. While the ultimate outcome of these inoperable cases is determined by the sensitivity of the lesion to roentgen therapy, the earlier course is completely dependent on the efficacy of the "by-passing" procedure. Ventriculocisternostomies[2] have been widely and successfully employed in the relief of this type of obstructive hydrocephalus; at times subtemporal decompression[3] has also been advocated. We have occasionally employed ventriculocisternostomy in conjunction with splitting the tentorial ring when we felt that there was blocking of the cerebrospinal fluid pathways at that site as well as at the aqueduct of Sylvius.

In 1952, when we presented the technique of ventriculo-suprahepatic anastomosis in the treatment of primary hydrocephalus,[1] we also mentioned the use of ventriculo-pleural shunt in similar conditions. We are still studying these methods in the treatment of hydrocephalus but feel that a longer follow-up period is desirable before reporting on our results. Ventriculo-pleural anastomosis, however, is a relatively simple and easily performed procedure so that its use in the treatment of secondary hydrocephalus complicating midline cerebral neoplasms seemed worth a trial.

The following is a brief report of 6 consecutive cases of obstructive hydrocephalus secondary to neoplasms in which ventriculo-pleural anastomosis proved successful in relieving the increased intracranial pressure for at least the limited period of time required in these instances.

OPERATIVE TECHNIQUE

Under intratracheal anesthesia, the right occipitoparietal burr hole used for ventriculography is reopened and a #10 rubber catheter or a plastic tube of similar diameter is inserted into the ventricle. Three or four holes have previously been placed in the terminal 3 cm. of the tubing. After firmly suturing the tube to the periosteum at the burr hole, the other end of the tubing is carried through a subcutaneous tunnel along the posterior aspect of the neck and right upper thorax to the region of the 4th or 5th intercostal space. In this region, through a 2 to 3 inch incision, the pleura is exposed, and when all is in readiness a small stab is made in the parietal pleura. Tubing with three holes in the terminal 3 cm. is then passed into the

pleural cavity for a distance of 6 to 8 cm. The lung is re-expanded and all incisions are closed in the usual manner. It is usually necessary to make a small incision at the base of the neck in order to facilitate passing the tube through this region. Postoperatively the head is kept at all times at least at a 30° elevation in order to insure a constant flow of fluid through the shunt.

CASE REPORTS

Case 1. E.H. *Anterior 3rd ventricle tumor. Relief of pressure for 14 months after V-P anastomosis and x-ray therapy.*

A 4-year-old boy was admitted with a history of rapidly developing blindness associated with severe papilledema, nausea and vomiting.

Ventriculography on Oct. 10, 1952 demonstrated an anterior 3rd ventricle tumor which on craniotomy proved to be an astrocytoma.

Postoperatively it was obvious that the patient still had ventricular obstruction, and on Oct. 17, 1952, after several days of ventricular drainage, a right ventriculo-pleural anastomosis was carried out.

He has received several courses of x-ray therapy. There has been no change in the preoperative blindness, the fundi now showing marked atrophy. However there has been no recurrence of the signs or symptoms of increased intracranial pressure and the child is able to attend a school for the blind.

Case 2. M.T. *Posterior 3rd ventricle tumor. Signs of progression of tumor without recurrence of increased pressure 6 months after V-P anastomosis.*

A 13-year-old girl was admitted with a 4-month history of headache, unsteadiness, involuntary movements of the right arm, nausea and vomiting. Examination showed severe papilledema associated with almost complete blindness, a right dysmetria, bilateral Babinski sign, and extreme drowsiness.

On May 25, 1953 a ventriculogram demonstrated a posterior 3rd ventricle tumor, and a lamina terminalis and third ventriculostomy were performed.

After several days it became obvious that the patient was still suffering from increased intracranial pressure so that on June 3, 1953 a right ventriculo-pleural anastomosis was carried out.

Since this procedure the patient has had no signs of increased intracranial pressure; she has, however, showed definite evidence of further tumor growth in spite of x-ray therapy.

Case 3. A.S. *Brain stem tumor. Relief of increased intracranial pressure for 6 months.*

A 43-year-old housewife was admitted with a history of progressive numbness of the left side of the face and a right hemiparesis of 10 months' duration. Pneumoencephalography revealed a picture typical of a brain stem tumor. The patient was started on x-ray therapy but after several weeks signs of acute ventricular obstruction developed.

A ventriculo-pleural anastomosis was carried out on June 10, 1953, with immediate subsidence of all signs of increased pressure.

During a 6-month follow-up period no new findings have developed.

Case 4. A.A. *Large 3rd ventricle tumor. Relief of increased pressure for 7 months.*

A 66-year-old woman was admitted with a 2-month story of headaches, confusion, and poor visual acuity. The patient was obtunded and disoriented. The fundi

could not be seen because of bilateral cataracts. Ventriculography on May 3, 1953 demonstrated a large nodular tumor mass filling almost the entire 3rd ventricle, and causing ventricular obstruction.

A ventriculo-pleural anastomosis was carried out on the same day and was followed by a course of x-ray therapy.

To date, Dec. 24, 1953, there has been no recurrence of her complaints.

Case 5. M.K. *Third ventricle tumor. Relief of increased pressure for 19 months in spite of signs of continued tumor growth.*

A 6-year-old boy was admitted with a progressive history of 13 weeks' duration characterized by headaches, vomiting and double vision. Examination revealed severe papilledema and a left 6th nerve palsy. Ventriculography on Mar. 24, 1952 was considered to show a tumor in the region of the pineal gland.

A ventriculo-pleural anastomosis was performed with immediate relief of the increased intracranial pressure.

The patient, in spite of x-ray therapy to skin tolerance, has shown definite signs of a progressive left hemiplegia without any further suggestion of increased intracranial pressure.

Case 6. V.F. *Relief of pressure signs for 7 months until death from tumor growth.*

A 16-year-old girl was admitted complaining of headache, tinnitus and episodes of numbness in the right arm. Examination showed a mild right hemiplegia and papilledema. On July 26, 1952 ventriculography was considered to demonstrate aqueduct stenosis.

After a negative posterior fossa exploration, ventriculocisternostomy was performed. Her signs of pressure continued.

On Aug. 23, 1952 a lamina terminalis and third ventriculostomy were performed. These procedures also failed to relieve the increased pressure.

On Sept. 12, 1952 ventriculo-pleural anastomosis was carried out.

The patient died 7 months later with the signs of a brain stem tumor that were not checked by x-ray therapy; there was no recurrence, however, of increased pressure.

Tabulation of cases

Case No.	Age	Site of Tumor	Length of Follow-up	X-ray Rx.	Outcome
1	4	ant. III v.	14 mos.	yes	good
2	13	post. III v.	6 mos.	yes	tumor regrowth; no pressure
3	43	brain stem	6 mos.	yes	good
4	66	III v.	7 mos.	yes	good
5	6	post. III v.	19 mos.	yes	tumor regrowth; no pressure
6	16	brain stem	7 mos.	yes	died; no pressure

DISCUSSION

The ability of the pleural surfaces to absorb cerebrospinal fluid with a normal or elevated protein content is apparently fairly good. The first week or 10 days after a ventriculo-pleural anastomosis, x-rays will disclose a small amount of fluid in the pleural space; thereafter the chest is clear by x-ray as well as on physical examination. (We have had several instances when fluid

continued to accumulate in the chest; this did not occur in the patients with tumors.) Two possible explanations for the disappearances of fluid in the chest have occurred to us. First, the ability of the pleural surfaces to absorb fluid increases; second, there is an equilibrium established between the rate of production of cerebrospinal fluid and the ability of the pleura to absorb. While the latter explanation seems more likely to us, further study of this problem is being undertaken.

The use of an exteriorizing procedure that depends on extracranial reabsorption of the fluid has an important advantage over intracranial bypassing procedures in the treatment of hydrocephalus secondary to midline tumors. As these lesions grow there is always the possibility of compromising the subarachnoid spaces at the tentorial ring and along the base of the brain, thus making it impossible for the fluid to circulate even after it has been conducted around the blocked aqueduct or midline ventricle. This continued expansion of the tumor does not interfere with the working of an extracranial shunt. It is quite possible that this is the explanation of the failure of the Torkildsen procedure in Case 6.

It is also our feeling that the simplicity of this procedure and the speed with which it can be carried out is a distinct advantage in the handling of these patients, many of whom are quite ill.

SUMMARY

Six patients with obstructive hydrocephalus secondary to midline tumors were treated by ventriculo-pleural anastomosis. This procedure proved satisfactory in reducing the increased intracranial pressure for at least a period sufficiently long to allow an adequate dose of x-ray to be delivered to the tumor.

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ADDENDUM

In the intervening 4 months since this paper was submitted for publication, Cases 1, 3 and 4 have continued to do well. Case 5 has shown further deterioration, still without signs of increased intracranial pressure. Case 2 is of particular interest: this girl lapsed into coma and died in January, 1954, some 7 months after the ventriculo-pleural anastomosis. At autopsy there were no signs of increased intracranial pressure. The tumor proved to be a glioblastoma arising in an astrocytoma with extensive subarachnoid metastases. In addition there were widespread metastases in the right pleural cavity, the abdominal lymph nodes and the bone marrow of the sternum and vertebral bodies.

DECOMPRESSION OF THE TRIGEMINAL ROOT

PALLE TAARNHØJ, M.D.

Departments of Neurosurgery, The University Hospital (Rigshospitalet), and Bispebjerg Hospital,† Copenhagen, Denmark*

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In a preliminary communication[12] decompression of the trigeminal root was described as a treatment in trigeminal neuralgia. The paper reported the results in 10 cases with a very short follow-up. Since then this method has been used almost regularly in cases of trigeminal neuralgia in Copenhagen, and it has been introduced too in a number of clinics in other countries.

Up to the present the procedure has brought both some satisfaction and some disappointment. The disappointment has been that in some of the patients, as was apprehended in the first communication, the pain has recurred and a re-operation has been necessary. The satisfaction has been that the risk of this operation seems to be rather small in a larger series and that the procedure seems to be useful also in other hands.[1,3,5–11,13]

However, in some of the clinics where this surgical procedure has been tried, there has been doubt about certain technical details of the operation, and the technique has been modified.[1,5,6,9–11,13]

It is therefore felt justifiable to describe here the details of the technique used and to report on further experiences with the operation, with a warning against too much enthusiasm, as follow-up has shown that recurrence of the pain has occurred in at least some of the patients. It will be necessary to follow the patients for a long period before the actual percentage of recurrences can be established. It is felt that it still is too early to advocate this surgical procedure as one that should be used as a standardized operation at present.

THE MATERIAL

Up to July 1, 1953 a total of 76 patients have been treated in Copenhagen by decompression of the trigeminal root (Table 1).

The patients may be divided in three groups: (1) those with lightning-like shooting pain called typical trigeminal neuralgia, (2) those with the same kind of pain but who have besides this a more constant burning pain called atypical trigeminal neuralgia, and (3) those showing no tic pain but a more constant burning pain in some part of the face, called atypical facial pain.

The difference, if any, in etiology and pathogenesis between the diseases of the first two groups is small. Both groups suffer from what is usually called trigeminal neuralgia, and the results of the decompressive treatment indicate that the diseases in these two groups are related. On the other hand,

* Chief: E. Busch, M.D.

† Chief: B. Broager, M.D.

TABLE 1

Material

	Typical Trigeminal Neuralgia	Atypical Trigeminal Neuralgia	Atypical Facial Pain
Number of patients (76)	43	27	6
Men (32)	15	13	4
Women (44)	28	14	2
Average age	60 yrs. (29–79 yrs.)	56 yrs. (34–73 yrs.)	42 yrs. (29–63 yrs.)
Average duration of symptoms	7 yrs. (2 mos.–23 yrs.)	7 yrs. (1 mo.–25 yrs.)	11 yrs. (1–30 yrs.)
Right side	29	14	2
Left side	11	10	3
Both sides	3	3	1
1st branch	0	1	1
2nd branch	5	6	1
3rd branch	9	4	1
1st+2nd branches	9	4	1
1st+3rd branches	1	0	0
2nd+3rd branches	15	8	1
1st+2nd+3rd branches	4	4	1
Previous peripheral treatment	28	15	3
Previous trigeminotomy	1	1	0
Pre-operative "spontaneous" hypesthesia	7	10	1 (hemihypesthesia)

there are other differences in these two groups. In the second group, for instance, the percentage of men, the percentage of left-sided pain, and the percentage of what has been called "pre-operative spontaneous hypesthesia" seem to be higher than in the first group. The third, rather heterogeneous group seems to differ from the first two groups in regard to etiology, as indicated by the results of the treatment.

All patients except one were suffering from pain at the time of admission to the neurosurgical department. More than half of the patients had been treated previously with alcohol, exeresis, or electrocoagulation of the peripheral branches of the trigeminal nerve. Consequently some of the patients presented slight hypesthesia following this treatment, but other patients had "pre-operative spontaneous hypesthesia," i.e. slight hypesthesia in some part or another of the face, which was not caused by previous treatment. Two patients had been treated previously by partial trigeminotomy.

The patients in the first two groups were selected in no special way for operation. Practically all patients suffering from trigeminal neuralgia admitted to the neurosurgical departments in Copenhagen within the last $2\frac{1}{2}$ years

have been treated by decompression. The diagnosis in some cases may be difficult, and perhaps it has been wrong in some few cases in this series.

TECHNIQUE

The patients in this series have been treated in three different ways: (1) by temporal-intradural approach, (2) by temporal-extradural approach, and (3) by cerebellar-intradural approach. Most of the patients have been operated on by the author, some of them by other surgeons.

The temporal-intradural approach has been the standard method. Local anesthesia is used, usually with some Pentothal. The patients are placed on the back in a horizontal position with the head turned to the side. No hypotensive drugs are used and no lumbar puncture is performed.

The operation is performed through a vertical incision in the temporal region reaching the zygomatic arch and a small triangular craniectomy, about $1\frac{1}{2}'' \times 1\frac{1}{2}''$, just above the base of the skull, the temporal vessels being ligated and the soft tissues drawn apart with a self-retaining retractor. For a time the foramen spinosum was plugged extradurally, but now the author feels that the bleeding is about the same during the opening of the cavum Meckelii without this procedure, and in the last some 40 cases the foramen has not been plugged.

The dura mater is opened by a T-shaped incision and the wings of the cut dura mater are fixed to the muscle with a couple of stay sutures. The surface of the brain is covered by pieces of cotton and the temporal lobe is elevated from the base of the skull with a ribbon retractor. At the same time the head is lowered. Generally the veins running from the temporal lobe to the dura mater can be avoided, but in 20 cases in this series it has been necessary to cut one or more of the veins, which in no instance caused any postoperative complications.

The dura mater in the middle fossa is palpated with a forceps. Posteriorly the tentorium feels soft, and just in front of this the superior petrosal sinus is seen at the edge of the petrous part of the temporal bone. In some cases the superior petrosal sinus is very small and difficult to observe. The cavum Meckelii usually can be very easily located as the most lateral part of the middle fossa where the dura mater is not tightly bound to the base of the skull but soft and yielding to the palpating instrument—just in front of the superior petrosal sinus.

With a sharp knife and scissors the dural roof of the cavum is opened widely. Care must be taken not to injure the root-fibres and not to incise the cavernous sinus, which is directly medial to the cavum. If this happens, the lesion of the sinus may be plugged with gel-foam. The incision over the cavum is continued posteriorly above the trigeminal root through the superior petrosal sinus, which is divided between clips. For this purpose special scissors and clips-forceps are used, called Olivecrona's tentorium scissors and clips-forceps.* The bleeding from the sinus in some cases may be difficult to control, but diathermy should not be used. The diatherm is practically never used by the author at the base of the skull during this operation, as he feels it is important not to do so. There have been two cases of facial palsy following the use of diathermy in this region.

In most cases the tentorium then has been divided to its free edge, but attention must here be drawn to the trochlear nerve, which lies close upon the free edge of the tentorium and disappears into it just behind the superior petrosal sinus. Therefore,

* Made in Sweden by Stille.

the incision through the tentorium just behind the sinus should be made in a direction that is posterior and a little lateral for some centimetres and then turned medially to the edge. Even a very slight pull upon the nerve may cause a trochlear palsy.

At a re-operation upon one of the patients, who had recurrence after a decompression of the trigeminal root, it was found that the posterior angle of the tentorial incision, which in this case had not been continued to the free edge of the tentorium, had retracted in a forward direction since the first operation, and now was pressing upon the trigeminal root. The incision then was enlarged to the free edge, and the patient was free from pain. Therefore, as far as the author can see, an important advantage of the intradural approach is that one can cut the tentorium and in this way perhaps diminish the risk of recurrence. By the extradural approach it is difficult to cut back farther than the sinus. The author also feels that visualization is better by the intradural method, and that bleeding is less and more easily controlled. However, he has only seen the extradural approach used by others and has never tried it himself.

The temporal-extradural approach in many clinics has been the method of choice, but in this series it was used in only one patient. As in the Frazier[1] operation, the dura mater was stripped from the base of the skull to the middle meningeal artery, which was cut. The dura mater covering the trigeminal ganglion and the root was incised to the superior petrosal sinus, which was divided between clips. The dura mater between the root and the brain was incised just in front of the sinus in order to place the clips at the sinus.

The cerebellar-intradural approach. In some patients with trigeminal neuralgia in this series, suspected to have tumors in the cerebellopontine angle, a cerebellar approach was performed, but no tumor was found. The approach was the same as Dandy[2] used for trigeminotomy. An attempt then was made to cut the superior petrosal sinus and to perform a decompression of the trigeminal root by this approach, but it appeared to be very difficult and dangerous and did not succeed. A hook then was put into the porus trigemini—i.e. the opening where the root leaves the cavum Meckelii—and an attempt was made to enlarge the porus a little in different directions in order to free the root from possible adhesions. Although no real decompression was performed in the 5 patients treated in this way, they were all free from pain after the operation, and the sensibility was normal.

Re-operations have been performed in 5 patients with recurrence of pain. At the first two re-operations the root was cut. The third case was the one mentioned above, in which the posterior angle of an incomplete tentorial incision was seen to press upon the trigeminal root. Consequently a better decompression was made. At the last two re-operations no explanation of the recurrence of pain was found. The root was covered by a thin new-formed membrane and surrounded by liquor from the neighbouring cistern. A new decompression was made with special care of the lateral part of the root in the porus trigemini. Postoperatively the patients became free from pain.

RESULTS

Typical and Atypical Trigeminal Neuralgia. In one patient (Table 2) the operation had no or very little effect. On recovery from anesthesia 7 patients for few days had some pain similar to the pre-operative pain. This happened

TABLE 2

Results

	Typical Trigeminal Neuralgia	Atypical Trigeminal Neuralgia	Atypical Facial Pain
Number of patients (76)	43	27	6
Type of operation:			
Temporal-intradural (70)	42	22	6
Temporal-extradural (1)		1	
Cerebellar (5)	1	4	
Follow-up after operation	3–27 mos.	1–21 mos.	11–20 mos.
Average follow-up	13 mos.	9 mos.	14 mos.
No effect		1	3
Recurrences	4	3	2
Few minor attacks	3	4	
Some uncharacteristic pain	3	4	
No pain	33	15	1
Re-operation with trigeminotomy	1	1	
Re-operation with decompression	2	1	

especially in the early cases of the series, in which the operations occasionally were troublesome and some contusion of the root may have occurred.

The remainder of the patients with trigeminal neuralgia were free from pain on recovery from anesthesia. Nine of the 17 patients with "pre-operative spontaneous hypesthesia" had normal sensation in the previously hypesthetic area after the operation, which may indicate that the "spontaneous hypesthesia" and perhaps the neuralgia had been caused by a slight compression of the trigeminal root.

At follow-up, which still is short, 4 patients have presented real recurrences of tic pain, usually with the same localization as pre-operatively, so that a re-operation was needed. The recurrences in these 4 cases arose 9 months, 9 months, 5 months, and 2 weeks after the first operation. Three patients have had a partial recurrence of pain 18 months, 2 months, and 2 days after the operation, but in 2 of these cases pain soon disappeared again. Some patients have had a few minor attacks of tic pain, but no further treatment has been necessary. Some other patients have presented uncharacteristic pain and sensations in the face, but only one needed treatment (vitamin B_{12}).

Atypical Facial Pain. The decompression of the trigeminal root was developed as a treatment for trigeminal neuralgia. For another group of patients, those with atypical facial pain, no satisfactory treatment is available. It therefore was felt reasonable to try decompression of the trigeminal root in some of these patients. The results, however, were disappointing in nearly all cases. In some of them the operation, just as many other kinds of treat-

ment in these patients, brought about a temporary release, after which the pain recurred. Only one patient with atypical facial pain in this series—and recently one more—were relieved of pain. Both were young women who presented what is usually termed supra- and/or infra-orbital neuralgia, i.e., a constant burning pain localized on one or both sides to the areas of the supra- and infra-orbital nerves with local tenderness of the nerves. The first of these patients, who was operated upon 1 year ago, had pain on both sides, and both sides were decompressed, since previously alcohol injections in the nerves had had good effect for some time. These are the only 2 patients with supra- and infra-orbital neuralgia who were treated by decompression. Another patient in this group had probably a zoster neuralgia. He was the only elderly person in this group.

COMPLICATIONS

Usually the patients stand the operation well. In most cases they are sitting up in bed the day after operation, and on the third day they are out of bed.

In 2 patients auricular fibrillation developed postoperatively; it was controlled by digitalis. These were the only severe postoperative complications pertaining to the general condition of the patients.

The most common complication has been severe headache for some time. Another common complication has been palsy of the trochlear nerve, which occurred in 15 patients. In by far the greatest number of these the palsy disappeared after a couple of months; in some cases it persisted for more than half a year before receding, and in a couple of cases it has remained stationary.

The patient operated upon by the extradural approach presented a postoperative trigeminal anesthesia which disappeared within some time. Four more patients have shown some hypesthesia after the operation.

In 2 cases in which diathermy had been used at the base of the skull there was a transitory palsy of the facial nerve.

In 1 patient a transitory aphasia developed. He had been operated upon several years earlier with partial trigeminotomy by an extradural temporal approach. He then had recurrence of his tic pain and a decompression by the intradural approach was performed. The temporal lobe was markedly adherent to the dura mater at the base of the skull, and some contusion of the lobe was unavoidable. This case shows that even an extradural approach may cause subdural adhesions from contusion of the temporal lobe. It is therefore doubted by the author that the extradural approach is more safe than the intradural, as has been suggested by others. Finally one patient had slight paraphasia for some days; no veins passing from the temporal lobe to the base of the skull had been cut in this case.

SUMMARY

Further experiences with decompression of the trigeminal root are presented together with some remarks on the surgical technique.

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THE INCREASING IMPORTANCE OF LUNG CANCER AS RELATED TO METASTATIC BRAIN TUMORS

EDWIN M. KNIGHTS, JR., M.D.
Henry Ford Hospital, Detroit, Michigan

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THE importance of careful survey of the lungs in patients with symptoms of cerebral neoplasm has long been recognized. Concomitant involvement of the lungs and brain by tumors metastasizing from other organs is, of course, a very frequent occurrence, and primary lung tumors are well known for their tendency to metastasize early to the brain.[4,7,8,10,11,16,21,22,24,25]

In view of the findings of many investigators that bronchogenic carcinoma has been undergoing an absolute increase in frequency,[1,2,4–6,8,9,12–14,15,17–19,23,26,28,29] a survey has been made of autopsies and surgical specimens at Henry Ford Hospital during a 26-year period ending in 1953 in an attempt to determine whether any significant changes occurred in the relative importance of lung cancer as a primary site of metastatic cancer in the brain. Approximately 6900 autopsies were reviewed in this study, and only tumors whose identities were established by histological examination were included in this series.

FINDINGS

There were 102 metastatic brain tumors, 64 occurring in males and 38 in females. The distribution of primary sites in males and females is shown in Figs. 1 and 2. The most common primary site in males was lung, accounting for 21 of the 64 cases. No other cancer approached lung tumors in importance. In females, the findings differed somewhat. Nineteen of the 38 metastases, or exactly half, had originated in the breast, while lung cancer (4 cases) was next in frequency. It should not be overlooked, however, that 33 other varieties of cancer involved the brain, either by metastases or, occasionally, by direct extension.

A study of the percentage of all autopsies showing primary cancer of the lung over the 25-year period from 1928 to 1953 gave the following findings:

1928 to 1933	0.7 per cent
1933 to 1938	1.0 " "
1938 to 1943	1.3 " "
1943 to 1948	2.3 " "
1948 to 1953	3.2 " "

When the percentage of pulmonary cancer in males alone was compared with the percentage of all cancer found in males during the same period, the increase was even more striking:

1928 to 1933	5.6 per cent
1933 to 1938	5.7 " "
1938 to 1943	7.8 " "
1943 to 1948	17.2 " "
1948 to 1953	16.4 " "

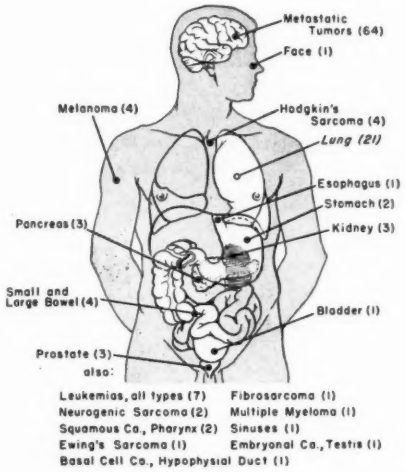

FIG. 1. Primary sites of 64 metastatic brain tumors in males.

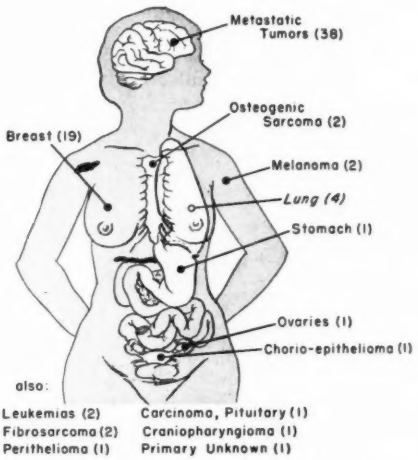

FIG. 2. Primary sites of 38 metastatic brain tumors in females.

While there was also an increase in cases of neoplasms of the breast autopsied during this period, there was not the same relative increase in proportion to other tumors in the female as was shown by lung cancer in the male, and the increase was more in line with the over-all increase in autopsies in cases of carcinoma of all types. Statistics over the same 25-year period revealed the following rise in percentage of breast cancer found in all autopsies:

1928 to 1933	1.1 per cent
1933 to 1938	1.4 " "
1938 to 1943	1.9 " "
1943 to 1948	1.4 " "
1948 to 1953	2.4 " "

Figs. 3 and 4 demonstrate how frequently there was primary or secondary involvement of the lungs by cancer associated with metastatic brain tumors. In males, in whom 64 metastatic brain tumors were found, 21 cases of primary lung cancer, plus 28 cases of secondary metastatic lung involvement resulted in lung lesions in 77 per cent of the cases. Of the 38 females, among whom there were only 4 primary lung cancers, 24 had metastases to the lung, so that the lungs contained cancer in nearly 74 per cent of the cases.

Primary lung cancer was found to have metastasized to the brain in 55 per cent of the cases in which a study of the cranial cavity was permitted. The metastasizing cell types included 9 undifferentiated carcinomas, 7 squamous cell carcinomas, 7 adenocarcinomas, 1 alveolar cell carcinoma, and 1 of undetermined type.

The great majority of the metastases were multiple, often tending to lodge in the subcortical area, as was found by Rich[20] and Baker.[3] As Willis[27] pointed out, the frequency of growths in this situation can probably be at-

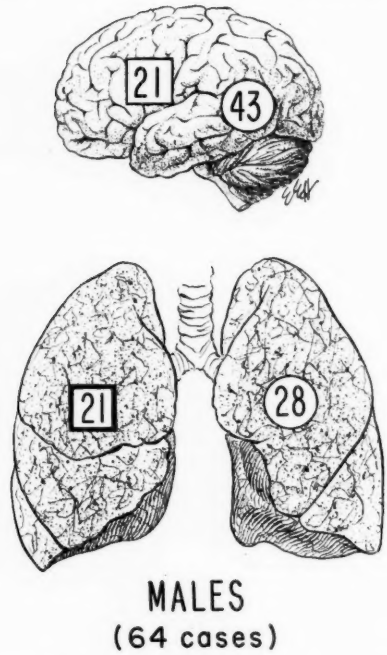

FIG. 3. Relationship of lungs to metastatic brain tumors in males. *Squares:* primary lung cancer which metastasized to brain. *Circles:* secondary cancers which involved lungs and brain.

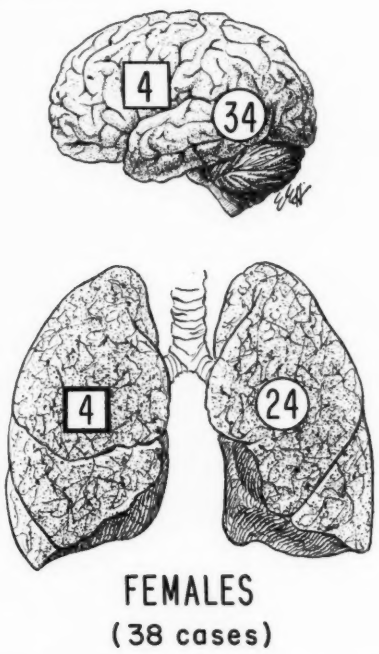

FIG. 4. Relationship of lungs to metastatic brain tumors in females. *Squares:* primary lung cancer which metastasized to brain. *Circles:* secondary cancers which involved lungs and brain

tributed to the rich vascularity of the cortical gray matter and to the arrangement and caliber of vessels in this zone. Three solitary metastases occurred—1 adenocarcinoma, 1 squamous cell, and 1 undifferentiated carcinoma.

CONCLUSIONS

Pulmonary carcinoma, which very definitely seems to be undergoing an absolute increase in frequency, accounted for almost one-fourth of the metastatic tumors of the brain in this series, and must be given very serious consideration in attempting to locate the primary site of a metastatic lesion. Carcinoma of the breast, however, is the most frequent primary site in females, and accounted for exactly half of the metastases in the females in this series. The necessity of careful study of the lungs in patients showing symptoms of cerebral tumors was further emphasized by the finding of either primary or secondary cancer in the lungs of 77 of the 102 patients.

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CASE REPORTS

LIPOMA PRODUCING A LESION OF THE DEEP BRANCH OF THE RADIAL NERVE

CASE REPORT

CHARLES S. CAMPBELL, M.D.,* AND ROBERT F. WULF, M.D.
Salem, Oregon

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Nontraumatic lesions of the deep branch of the radial nerve in the forearm are apparently not common and have seldom been reported.[2] A case exhibiting damage to the deep branch of the radial nerve,† caused by pressure of a lipoma on the nerve in its course in the supinator muscle of the forearm, is herewith presented.

CASE REPORT

A single white female, aged 40, who was a church worker, complained of noticing a lump at the outer side of the left forearm 3 months before admission. At about the same time she noticed that she could not use the left index finger properly, and after several weeks she noticed that the finger would not extend completely. There was no unusual sensation in the finger except "a little numbness." She had some intermittent pain in the front and back of the upper arm, and she thought she could bring on this pain by pressure over the lump in the forearm.

She had suffered from chronic back pain for years and had an x-ray abnormality in the 3rd lumbar vertebra which was thought to be congenital, perhaps a hemangioma. Her family history was noncontributory.

Examination. Positive neurological findings were limited to the left arm. The index finger and the thumb could not be completely extended (Fig. 1). There was a deep swelling on the forearm in the general area of the supinator muscle. This swelling was soft on palpation and not readily movable. There seemed to be some weakness of the dorsiflexors of the wrist (extensor digitorum communis muscle). The wrist drop test and the brachioradialis test[3] gave a normal response, indicating that there was no lesion of the radial nerve above the forearm. Careful study for sensory changes showed only equivocal decrease in sensitivity to light touch, pain, and pressure over a small area at the dorsum of the metacarpophalangeal joint of the index finger.

The neurological findings indicated a lesion of the deep branch of the radial nerve. This nerve supplies the following muscles: extensor digitorum communis, extensor digiti quinti and extensor carpi ulnaris. At a more distal level it gives branches to the abductor pollicis longus, extensor pollicis longus, extensor pollicis brevis, and extensor indicis proprius.[1]

Operation. The tumor was exposed through a vertical incision 4 inches long, just to the ulnar side of the brachioradialis muscle, which was retracted laterally, exposing the superficial branch of the radial nerve. The vessels in this area supplying the brachioradialis muscle were divided and ligated to further expose the supinator muscle and the common radial

* 1280 Center Street, Salem, Oregon.

† Properly termed: ramus profundus nervi radialis (O.T. posterior interosseous nerve) or often called dorsal interosseous branch.

FIG. 1

nerve, showing its superficial branch and its deep branch. The deep branch was then followed distally to where it perforated the supinator muscle. The nerve was retracted laterally, and the upper, thinned-out, atrophic fibers of the supinator muscle were incised to expose the lipoma located beneath it. The lipoma extended laterally around the outer aspect of the head of the radius, forcing the deep branch of the radial nerve anteriorly and laterally.

The tumor was thought to have arisen near the periosteum of the ulnar aspect of the radius or the interosseous membrane.

Microscopically it was a typical lipoma.

Course. The surgical wound healed by primary intention. At the time of this writing a sufficient period has not elapsed for recovery of nerve function.

SUMMARY

A case is described of a lipoma producing paralysis of the deep branch of the radial nerve.

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BRAIN ABSCESS CAUSED BY NOCARDIA ASTEROIDES

OSCAR A. TURNER, M.D.

Department of Neurological Surgery, Youngstown Hospital Association, Youngstown, Ohio

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Although as late as 1945[1] infections of the central nervous system with Nocardia asteroides were considered rare, an increasing number of cases both of metastatic involvement from pulmonary disease[5] and occasionally of primary infections[2] are being reported. This is of interest to the neurosurgeon since brain abscess is said to be a complication in from one-third to one-half of the cases in which the primary infection is in the lung.[3] As in Actinomyces bovis almost any part of the body may be involved, but Stevens[4] in the most recent review of the subject pointed out that Nocardia, while rare, is more virulent, spreads by the hematogenous route, and is more likely to involve the central nervous system.

Only occasional cures of brain abscess have been reported.[4] The organism is a Gram positive aerobic fungus which is generally considered to have some sensitivity to the sulfonamides, but a considerable variability exists in individual cases in the response both to the sulfonamides and antibiotics. With the use of chemotherapy and antibiotics as an adjunct to surgery, it seems worthwhile to record additional experiences.

CASE REPORTS

Case 1. A 15-year-old boy was first admitted on Oct. 6, 1950. Two weeks previously, his left arm and leg had suddenly become numb and his left leg would not support his weight. These symptoms lasted only a few hours, but were followed by frontal headache, more severe on the right. The headaches became increasingly severe and 4 days after onset he had episodes of vomiting, lethargy, and drowsiness. Intermittent diplopia developed, and 2 days before admission he had his first generalized convulsive seizure.

Past history was not remarkable; he had been in good health with no history of ear infection or pulmonary disease. He was right-handed.

Examination. Temperature was 97.6, respiratory rate 18 per min., pulse 64 per min., and B.P. 108/70. He was well nourished but so drowsy that at times it was difficult to obtain any verbal response. He had bilateral papilledema of the optic disc of 3 D. on the right and about 1 D. on the left. There were fine nystagmoid movements on lateral gaze, and definite weakness of the right internal rectus muscle with difficulty in fixing the eyes in full adduction. He had a mild left hemiparesis, greater in the lower extremity. Movements of the left upper extremity were extremely awkward and in the finger-to-nose test he had considerable dysmetria. There was unsustained ankle clonus on the left and a marked Babinski sign. Severe nuchal rigidity was present. The sensory disturbance was that of a hypesthesia which involved the entire left side of the body including the face.

X-rays of the skull revealed no significant abnormality. X-rays of the chest disclosed a few minute calcifications in the upper third of the right lung with no evidence of active disease. Urinalysis was normal. He had a mild leukocytosis and the blood serology was negative.

Operation. On the day after admission ventriculography was done and a large abscess cavity in the right parietal region was entered at a depth of 4 cm. Twenty cc. of greenish-yellow pus were removed and 3 cc. of pantopaque introduced before withdrawal of the needle. A small bone flap was reflected in the right superior parietal region. The exposed brain had some pallor but was not otherwise unusual. A thick-walled abscess was easily enucleated through an incision in the cortex, the adjacent brain being relatively avascular (Fig. 1).

Course. The drains were removed in 24 hours, and the wound healed well without evidence of infection. He continued to have increased intracranial pressure and on Oct. 21, 1950, 2

weeks after operation, the spinal fluid pressure was still between 300 and 400 mm. of water. At the time of discharge from the hospital on Nov. 8, 1950, there was still mild papilledema and the bone flap was slightly elevated.

Bacteriological Studies. A stain of the pus obtained at operation disclosed a very occasional Gram positive small bacillus but no other organism. The culture was sterile for bacterial growth but a fungus grew out on incubation at room temperature. An acid-fast stain of the pus disclosed no tubercle organism. The fungus isolated from the culture was sent to Dr. David T. Smith at Duke University and was reported as Nocardia asteroides. At the suggestion of Dr. Smith, sulfamerazine therapy was started with blood levels maintained between 14 and 18 mg. per cent.

FIG. 1. *Case 1.* Photograph of abscess and attached segment of overlying cortex removed at operation.

Pathological Report. The abscess measured 4.5 cm. in diameter and had a thick, well formed capsule (Fig. 1). The wall of the abscess was composed mainly of mature fibrous tissue with areas showing various stages of organization of fibroblasts and capillaries. There were numerous foci of acute inflammation outside of the wall, these being composed of neutrophilic leukocytes, and some lymphocytes and plasma cells (Fig. 2).

Course. The patient continued to show evidence of infection, with progressive papilledema, episodes of numbness and tingling of the entire right side of the body, and finally spontaneous vomiting.

2nd Admission, Nov. 18, 1950. Pneumoencephalography was done with the introduction of 60 cc. of filtered helium. The right ventricle was quite small, with the gas confined to the posterior portion of the body and temporal horn. The left ventricle showed good filling with no significant distortion of the midline structures. At this time the spinal fluid pressure was 385 mm. of water, and the fluid was quite clear and colorless.

3rd Admission, Dec. 20, 1950. There was papilledema of from 4 to 5 D. with numerous retinal hemorrhages in both fundi. He had slight facial weakness on the right, a fanning response on plantar stimulation on the right, and the bone flap was elevated more than it had been.

Aspiration through one of the previously placed trephine openings yielded 4–5 cc. of pus and on Dec. 23, 1950, the bone flap was removed. The dura mater was opened, with exposure of a large abscess which had formed in the cavity from which the previously encapsulated abscess had been removed. There was no definite capsule, and drainage was established through a stab-wound in the scalp.

Up to this time the patient had been receiving sulfamerazine, maintaining a blood level of from 10–11 mg. per cent. Because of lack of response, the medication was changed to sulfadiazine in large amounts, with a blood level which reached 20 mg. per cent on one occasion.

On Jan. 2, 1951, there was seen the first evidence of spread of the infection with the development of progessive lymphadenopathy in the cervical region. The wound, which had been healing well, began to break down and multiple sinuses appeared along the suture line. The dissolution of the suture line was progressive with the development of a large cerebral fungus. Mycelia could be identified in smears from the surface of the protruding granulomatous mass Aspiration of the cerebral fungus again localized an abscess.

4th Admission, Jan. 20, 1951. The granulation tissue over the abscess was incised with the

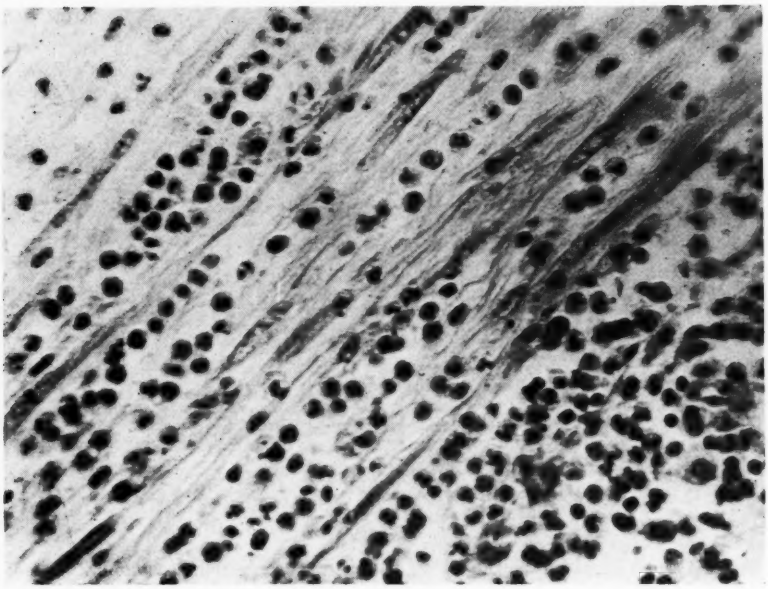

FIG. 2. *Case 1.* Photomicrograph showing details of inflammatory process in outer layers of abscess wall and adherent tissues.

electrosurgical unit and the abscess cavity was again drained and packed with sulfathiazole powder. He was now receiving sulfathiazole as well as potassium iodide. Nocardia asteroides was again grown from the pus and tests showed a possible sensitivity to aureomycin and terramycin. He was discharged from the hospital receiving terramycin, 500 mg. 4 times a day.

Course. The patient was seen at frequent intervals. Several lumbar punctures were done, with intraspinal pressures recorded as high as 500 mm. of water. The fluid was yellow and on occasions the pleocytosis reached between 2,000 and 3,000 cells, of which approximately 70 per cent were polymorphonuclear leukocytes.

5th Admission, Mar. 26, 1951. At this time he had nuchal rigidity, headache and elevation of temperature. It seemed likely that most of the hemisphere was the site of a chronic granulomatous infection. The patient expired on Apr. 9, 1951.

Autopsy. Gross findings. The significant findings were chronic granulomatous meningoencephalitis with abscess formation in the right parieto-occipital area. There was no evidence of specific inflammatory disease in the lungs, and the other organs were essentially normal.

There was marked herniation of brain through the operative site with adhesions between the fungating cerebral tissue, the scalp, and the edge of the bone defect. The base of the brain was covered with an abundant translucent greenish-yellow gelatinous exudate and a marked pressure cone involved the tonsils of the cerebellum and the brain stem. There was a purulent ependymitis which had extended to involve the right temporal lobe, where an area of inflammatory softening and cystic degeneration communicated with the inferior portion of the right temporal horn. Sections through the site of the fungus disclosed hemorrhagic tissue which was in places bright yellow and in other areas brown and somewhat glassy in appearance. The area of inflammation extended medially to compress the posterior portion of the body of the ventricle and measured about 7 cm.×5 cm. (Fig. 3).

Microscopic examination disclosed a diffuse meningitis which was most severe at the base

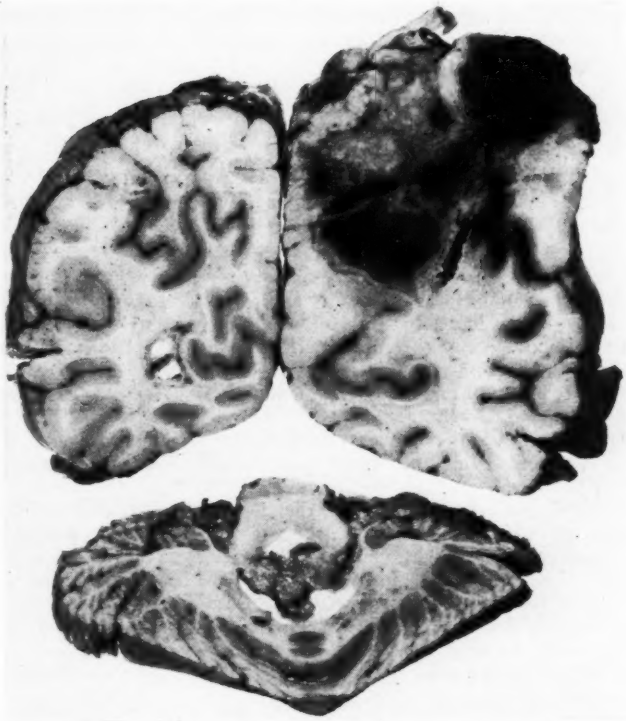

FIG. 3. *Case 1.* Cut section of brain showing character and extent of the inflammatory process. Note involvement of the structures about the 4th ventricle.

of the brain and over the area of cerebral fungus. The infiltrate was composed of lymphocytic cells, particularly plasma cells and monocytes, many of which were distended and some of which contained punctate basophilic masses. In some areas polymorphonuclear leukocytes were present.

While the most severe reaction was in the area of abscess formation and about the base of the brain, the suppurative process had extended to involve the ependymal lining of the ventricles, the subependymal tissues and the choroid plexus. There were compact masses of inflammatory cells forming foci closely resembling tubercles. These foci contained a core of distended histiocytes and monocytic cells with a surrounding area of lymphocytes and plasma cells. The perivascular infiltration was particularly evident in the subependymal tissues. Areas of necrosis, hemorrhages and inflammation were evident in the subcortical tissues.

The lungs showed some evidence of a nonspecific inflammatory process while the remaining organs were normal.

Comment. In this case therapy with antibiotics and sulfonamides proved to be totally ineffective. Penicillin, terramycin, sulfamerazine, sulfadiazine, and sulfadiazole were used with adequate blood levels.

It is of interest that spinal fluid smears and cultures taken as late as 4 days prior to the patient's death were sterile and failed to reveal any filamentous structure.

Blood cultures on three separate occasions were sterile and throat cultures grew out only a hemolytic Staphylococcus albus. On almost every occasion smear of the pus showed mycelia and at no time did the cultures give rise to any bacterial growth.

Autopsy failed to disclose a primary source for the infection other than the nervous system, although there was local lymphatic spread terminally from involvement of the scalp. The removal of a well encapsulated abscess at the first operation had suggested a good prognosis but the course of the illness thereafter was indicative of progressive involvement by the organism, a course that was never influenced by chemotherapy or antibiotics.

Case 2. A 31-year-old man was admitted on Dec. 16, 1952, with occipital headache of 2 weeks' duration. There had been some soreness about the right eye, but no visual disturbance and examination by an optometrist was said to have disclosed no abnormality. Three to four days before admission he began to suffer drowsiness, increasingly severe headache, and vomiting. At this time a mild upper respiratory infection with slight elevation of temperature had been treated with aureomycin. There was a vague history of convulsive movements of one side of the body but no history of muscular weakness, sensory disturbance, or speech disorder. The patient was right-handed.

The only past history was that of chest pain associated with a pleural effusion 1 year previously but no details concerning this illness were available. He also had had a furuncle of the neck.

Examination. The patient was extremely lethargic, but able to cooperate to a fair degree. B.P. in the right arm was 120/80, pulse rate 52 per min., and respirations 20 per min. There was 1 D. of papilledema of the right optic disc, and the disc margin on the left was blurred. There was minimal weakness of the facial musculature on the left. Babinski response was positive bilaterally. He had slight tenderness on percussion in the right frontal area. The neck was supple and there was no muscular weakness or sensory disturbance. During examination the patient vomited several times and had occasional hiccoughs. Laboratory studies revealed only a mild leukocytosis while x-rays of the skull and chest were normal in appearance.

Lumbar puncture revealed clear, colorless fluid, with an initial pressure of 400 mm. of water. The fluid contained 1 cell and gave a 1+ Pandy reaction, insufficient fluid having been removed for quantitative protein determination.

Course. Within a few hours after examination the patient's condition began to deteriorate rapidly. He became totally unresponsive and respiratory irregularity developed. Ventricular puncture was attempted through occipital trephines, but the right ventricle could not be entered. A small amount of air in the left ventricle showed the system to be shifted to the left. During the operative procedure respiratory arrest developed and he expired within a short time.

Autopsy. Gross findings. The cerebral convolutions were flattened and there was evident softening of the right frontal region. Upon removal of the brain the right frontal cortex ruptured, exuding considerable yellow creamy pus. There was no gross reaction in the leptomeninges over this abscess.

Section of the brain revealed multiple abscesses in the right frontal lobe. The largest measured 3 cm. in diameter; it seemed to have a moderately well developed capsule. Surrounding it were three smaller abscesses, the largest of which measured 0.7 cm. in diameter. The total area involved by the inflammatory process measured approximately 4.5–5 cm. in diameter. There was hemorrhage in the right internal capsule, midbrain, and lower pons, with punctate hemorrhages in the cerebellar peduncles.

Examination of the lungs disclosed a relatively small fibrotic area which involved the pleura and parenchyma of the right apex. There was slight enlargement of the peribronchial and mediastinal lymph nodes. The remaining organs appeared normal except for some passive hyperemia.

Microscopic findings. The largest brain abscess had a poorly formed, almost nonexistent capsule, the wall of which was formed by a narrow band of moderately compressed cerebral

tissues sparsely infiltrated by polymorphonuclear leukocytes and lymphocytic cells. In this area capillaries were numerous and the appearance was that of a granulomatous type of inflammation with plasma cells predominating.

At some distance from the abscess there were scattered discrete foci of exudate and infiltration suggesting multiple abscesses in various stages of formation. The pia arachnoid over the abscess showed acute inflammatory response with some thickening and infiltration. There were scattered areas of encephalomalacia and edema but no evidence of a diffuse inflammatory process throughout the brain. Special stains failed to reveal any tubercle bacilli and no mycelia could be identified.

Sections through the lung tissue in the right apex showed thickening of the pleural surface with dense fibrous tissue containing foci of lymphocytic accumulations. Beneath the pleural surface were large clusters of lymphocytic cells, may of these containing a central area of epithelioid cells surrounded by fibrillar material. These tubercle-like formations were widespread beneath the fibrotic pleura and present in the parenchyma at some distance from the pleural surface itself. No giant cells were seen and acid-fast stains failed to reveal tubercle organisms or fungi. The histologic changes in the lungs were those of a granulomatous inflammation of the right apex associated with hyperplasia of the bronchial epithelium and unresolved pneumonitis. Proliferative arteritis and focal fibrosis were also present.

Histologic examination of the remaining organs of the body disclosed no significant abnormality.

Material taken from the abscess at the time of autopsy and cultured for tubercle bacilli revealed within 1 week a pure growth of Nocardia asteroides.

Comment. Although the patient expired before any therapy could be established, this case represents the most frequent complication of pulmonary involvement. It is of interest in that the local pulmonary lesion was relatively silent other than one episode of pleural effusion 1 year before the cerebral manifestations occurred.

DISCUSSION

At the present time infections with Nocardia asteroides cannot be considered as rare and are being recognized as an entity somewhat apart from the more frequently encountered actinomycosis caused by Actinomyces bovis. Adequate therapeutic measures for infection of the nervous system have not yet been established, and Stevens[4] lists only 3 cases from the literature and 1 of his own as cures, 2 of these having had follow-up studies for only 7 months.

There has been considerable individual variability in the response of the organism to chemotherapy and antibiotics, and though the sulfonamides seem to have the best effect, this is neither constant nor adequate.

While results of treatment in cases of infection with Actinomyces bovis seem to be improving to some degree, particularly when the infection is outside of the nervous system, the prognosis for nocardiosis still remains poor. This despite the fact that histologically the tissue response to invasion by the two organisms is practically identical. It is of interest that in Case 1 the inflammatory process could be identified in the outer wall of the abscess and in the adherent tissue, despite the well-organized character and thickness of the capsule. Thus, while extension of the infection probably occurred from spillage, it might well have been the result of direct extension.

SUMMARY

Two cases of brain abscess caused by Nocardia asteroides are reported, one of apparently primary origin, and the other secondary to pulmonary disease.

In the first case surgical removal of the abscess in combination with the use of

sulfonamides and antibiotics failed to halt the spread of the infection, and death resulted from recurrent abscess formation and meningitis. In the second case death occurred before any definitive therapy could be instituted, and the abscess, which at autopsy was poorly localized and poorly encapsulated, proved to be of pulmonary origin. In this case both the pulmonary disease and the cerebral extension were quite insidious.

I wish to acknowledge the kindness of Dr. David T. Smith, and Dr. Norman F. Conant, of Duke University, for their generous assistance in identifying the organism in the first case and for their suggestions in reference to therapy.

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CEREBRAL PARAGONIMIASIS

R. S. Hooper, M.S., F.R.C.S.
Royal Melbourne Hospital, Victoria, Australia

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Cerebral abscess caused by fluke infestation is a rare event outside the areas where these parasites are endemic. Though invasion of the brain by Schistosoma japonicum is seen from time to time, and removal of these lesions has been reported by Shimidzu,[7] Greenfield and Pritchard,[3] and Speigel,[8] the related condition of paragonimiasis appears to be less frequently considered. Only a few reports of successful surgical removal of such a lesion were found in the literature. The first was by Kawai,[4] who described the case of a native of Japan. A diagnosis of pulmonary infestation by Paragonimus westermanii had been made on clinical and radiological findings, when he presented signs of a cerebral lesion. Another case of successful removal was reported by Busch and Cooper.[2] Their patient was a Korean, and a provisional diagnosis of a cerebral glioma had been made. Mitsuno *et al.*[6] reported 3 additional cases. The patients were Japanese children, 7, 9½ and 14 years of age. Two (Cases 2 and 3) were still well 6 months after operation. The third (Case 1) made an excellent immediate recovery but died 3 months later from "meningitis". A clinical diagnosis of brain tumor had been made in each instance.

The present report concerns a merchant seaman whose clinical picture was suggestive of a frontal lobe abscess secondary to a frontal sinusitis.

CASE REPORT

C.Y.C., a Chinese seaman, was admitted on Oct. 25, 1952. Although his comprehension of English was limited it was apparent that he was confused and, at times, irrational. The difficulties in obtaining a satisfactory history of his condition were thus considerable, and the information available from other sources at this time was limited.

Ten months previously he had undergone an operation for frontal sinusitis in Japan. He rejoined his ship, but during the last 3 or 4 months he again experienced frontal headaches and also complained of failing vision. While his ship was in Australian waters he again reported for treatment. Three weeks before his admission he was given intramuscular injections of penicillin and sulphonamides by mouth. No satisfactory remission of symptoms was obtained and 11 days later both frontal sinuses were again operated upon. The headaches became more severe and persistent, and vomiting had been frequent. He was admitted after being found in his room, lying beneath his bed in a confused state, with stiffness of the neck and fever.

Examination. The patient was drowsy, but at times he would be reasonably co-operative. Some irritability, photophobia, and stiffness of the neck were manifest. Recent scars of frontal sinus operations were seen below the orbital margins on each side and two smaller barely visible transverse scars were found above the left supraorbital ridge. The temperature was elevated to 100.2°F., while the pulse rate was slow (64). No abnormality of the chest or abdomen was found. There was gross bilateral papilloedema. The right pupil was markedly dilated and showed no reaction to light; the left was moderately dilated and a slight reaction to light was obtained. On the right the eye was almost completely immobile, a little abduction being present. On the left side all movements were full except abduction. A partial left facial weakness of the upper motor neurone type was present, together with slight diminution in power of the left arm and leg. No abnormality of sensation was demonstrable and the deep and superficial reflexes were all active, though the left tendon reflexes appeared slightly diminished. Both plantar responses were flexor.

A tentative diagnosis of a cerebral abscess in the right frontal lobe was made and the patient was taken to the theatre for immediate operation.

1st Operation. Under local anaesthesia burr holes were made in the right frontal and frontotemporal regions and the frontal lobe was explored with a brain needle. Although variations in the resistance to the needle could be felt, aspiration in a number of directions failed to produce any purulent material. Some cerebral tissue aspirated was smeared and stained, but no inflammatory elements were seen. The patient, never very co-operative, became very resistant to continuance of surgery under local anaesthesia and no further procedures were carried out at this stage.

Course. The following morning radiographs of the skull were obtained. These demonstrated a burr hole beneath the supra-orbital scar on the left side of the forehead, indicating that an attempt had been made to explore the left frontal region during the sinus operation that had been performed at least 10 months before. The frontal sinuses were irregularly opaque, but no definite evidence of osteomyelitis was seen. There was marked thinning of the posterior clinoid processes.

An EEG was obtained. The record was of low voltage but in occipital and parietal regions a flat 8–10/sec. wave was discernible. In the frontal regions irregular 1–2/sec. activity was seen but lacked localising features.

His condition remained unchanged and two days later ventriculography (Fig. 1) was performed. The radiographs revealed gross distortion of the lateral ventricles. The left frontal horn was large, while the right remained small and was displaced backwards and medially beneath the falx. The left lateral ventricle was generally larger than the right. The third ventricle lay about 0.75 cm. to the left of the midline.

2nd Operation. Following ventriculography, the patient was intubated under Pentothal and Scoline. With intermittent Pentothal and mechanically controlled respiration a right frontal osteoplastic flap was elevated and a dural flap was turned medially. The exposed surface of the brain was yellowish in colour; the convolutions were flattened but there was no abnormal convolutional pattern. The brain was needled in a number of directions and firm rubbery tissue was found towards the inferior surface of the lobe. A disc of cortex was first excised from the lateral aspect of the frontal lobe; during this procedure a small loculated abscess cavity was opened up, and below it an irregularly lobulated granulomatous mass could be felt involving the greater part of the lateral and lower aspects of the frontal lobe.

FIG. 1. Ventriculogram showing displacement and compression of the frontal horn of the right lateral ventricle.

Dissection around this mass was continued; on the lower and medial aspect another fluctuant mass was encountered and from this about 5 cc. of purulent material was aspirated and sent to the laboratories for examination. The smears of this material were found to contain ova which were recognized later as the ova of Paragonimus westermanii (Fig. 2). This last portion of the mass was dissected downwards where it passed under the frontal horn of the ventricle and was, in fact, adherent to it. As the mass appeared to extend posteriorly beneath the ventricle, it was felt reasonable, after complete aspiration of the contents, to leave this very small portion of the capsule in situ. All the remaining portions of the mass had, by this time, been completely excised. The remnants of the frontal lobe on the superomedial aspect were then resected. Haemostasis was obtained without difficulty, the dura mater was closed and the osteoplastic flap was replaced in the usual fashion.

FIG. 2. Microphotograph of one of the many ova found in the interior and the walls of the granulomatous mass. The operculated end, characteristic of the ovum of Paragonimus westermanii, is clearly seen.

Course. During the early portion of his postoperative course the patient ran an irregular temperature. There was some mental confusion and apathy but the degree was difficult to assess against a background of racial stolidity.

The weakness of the left side of the face and of the left hand was increased during the first week after operation. The power

subsequently improved but a noticeable lack of spontaneous movement in the left limb remained, and he was occasionally incontinent.

Three weeks after operation the patient was transferred to a convalescent hospital from which he returned for final review 3 weeks later. He was now much more alert and cheerful; though the left hemiparesis had improved further some weakness of the left hand and facial muscles persisted. He was then discharged for repatriation to his own country. Difficulties occurred and the delay provoked a psychotic outburst which necessitated certification.

Following the recognition of the ovum at operation a search was made for involvement of other organs. Radiographs of the chest revealed no abnormality and examination of the small amount of sputum produced revealed no ova. A complete blood examination showed a moderate leucocytosis, but there was no increase in the number of eosinophil leucocytes. Specimens of urine and faeces were searched for ova; none was found in the urine but the operculated ovum of Paragonimus westermanii was found in one specimen of faeces.

Further information of previous operations was obtained some time later. The frontal sinuses had apparently been subjected to two operations in the 2 years prior to his admission. On the first occasion purulent material had been obtained and at this time the cerebrospinal fluid pressure was high. An intracerebral abscess was suspected and the left frontal lobe was needled, but with negative results. Some months later a second frontal sinus operation was performed because a swelling had developed, first in the right orbit and then in the left. This information had not been available at the time of the frontal sinus operation in Melbourne when the frontal headache and the scars of a previous operation had suggested a recurrent infection; again, no active inflammation was found.

DISCUSSION

Paragonimus infestation of the brain is considered to be uncommon, even in the areas where this condition is endemic. The discovery and surgical excision of such a lesion in a country far removed from that in which the parasite is common must be a rare event, but the main interest in the case described lay in the difficulties in differential diagnosis from frontal sinusitis and intracranial extension of infection.

The geographical distribution of Paragonimus westermanii appears to be limited chiefly to China, Japan, Korea, Formosa and the Philippines.

Infestation is particularly prevalent in Korea and it is not unlikely that some troops engaged in hostilities in this area may become infected and, at a much later date, present a similar problem. Manson-Bahr[5] states that the disease occurred in some members of the U.S. Army engaged in the South Pacific during World War II. It seems probable that paragonimiasis must be added to schistosomiasis as the conditions most likely to cause intracranial involvement in those who have lived in the coastal areas of the West Pacific for some time.

The recent deployment of large numbers of troops in Korea with ancillary medical services has brought about more intimate knowledge of the clinical manifestations of paragonimiasis. Epidemic haemoptysis, the common manifestation of this disease, was not infrequently found among prisoners of war.

The following description of the parasite and the salient features in its life cycle are taken from Manson-Bahr:

"The fluke, *Paragonimus ringeri* (*westermanni*), is reddish-brown, thick and fleshy, oval, and measures 8–20 mm. by 5–9 mm. Development of the parasite proceeds in the fresh-water snail, *Melania*, and thereafter the larva, or metacercaria, encysts in several species of fresh-water crabs (*Potamon*) and crayfish.

"Man is infected by eating raw or improperly cooked crabs, of which the Koreans are very fond, while the raw juice of crayfish is taken as a medicine for diarrhoea and whooping cough. The young parasites hatch in the ileum and in 24–42 hours penetrate the intestinal wall near

the jejunum, reach the peritoneal cavity, and make their way to the diaphragm by penetrating the tendinous portion. Travelling beneath the pleura, the larvae reach and pierce the parenchyma of the lungs, where cysts are found. In other organs they do not reach perfect growth."

In the lungs the parasites form burrows or cysts of a reddish-brown colour, containing living or dead flukes together with pus in which are found ova and occasional Charcot-Leyden crystals. These cysts may ulcerate into a bronchus, causing haemoptysis, or sputum which is reddish-brown in colour.

Outside the lungs the flukes may become encapsulated and may even be destroyed. They incite an inflammatory reaction and the cavity containing the fluke may fill with purulent material which will also contain ova. Eventually the fluke dies but the cavity and the ova remain. This process may occur in the intestinal mucosa and here ulceration may occur so that the ova may later be found in the faeces. In the brain the process is the same,[1] and with the increasing inflammatory reaction and production of purulent material the lesion shows all the characteristics of a cerebral abscess. The route by which the parasite reaches the brain appears uncertain. Kawai,[4] citing Yokogawa,[9] suggested that the route to the brain is largely through the loose connective tissue of the perivascular spaces.

When such patients are seen outside endemic areas, presenting with cough, sputum and signs suggestive of an intracranial abscess, bronchiectasis with secondary cerebral abscess may be suggested. When no pulmonary manifestations are presented a cerebral glioma would probably be the tentative pre-operative diagnosis, as in the case reported by Busch and Cooper.[2] In the case presented here, the evidence of previous frontal sinus operations naturally suggested these as a source of the cerebral abscess.

Although cerebral manifestations of paragonimiasis are described in most textbooks, the reports by Kawai,[4] Busch and Cooper,[2] and Mitsuno *et al.*[6] appear to be the only papers describing surgical intervention and recovery from cerebral infestation. All of their patients had suffered from epilepsy and it would seem probable that cases presenting in this manner amongst Asiatics will suggest infestation with Schistosoma japonicum rather than Paragonimus.

The treatment of cerebral involvement would appear to be limited to those cases in which the patient has raised intracranial pressure. Apart from the ova, which merely provoke a foreign body reaction, the contents of the cysts or burrows are sterile. Even if some spilling of the contents does occur little harm would be done. Busch and Cooper[2] commented on the yellow colour of the brain, which was quite remarkable in the present case, and may be a point upon which diagnosis may be based.

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BILATERAL CAROTID-CAVERNOUS FISTULA

Captain T. H. Mason, M.C., U.S.A., Captain G. M. Swain, M.C., U.S.A., and Colonel H. R. Osheroff, M.C., U.S.A.
U.S. Army Hospital, Camp Gordon, Georgia

(Received for publication December 15, 1953)

The carotid-cavernous fistula presents an intriguing clinical and pathological picture. The specific surgical treatment has been recognized since 1809, when Travers[13] cured a patient with pulsating exophthalmos by ipsilateral common carotid ligation. A cirsoid aneurysm of the orbit was thought to have been the etiological factor. In 1823 Guthrie[4] recorded the autopsy of a patient with pulsating exophthalmos, who was found to have an aneurysm of the ophthalmic artery. Aneurysmal rupture within the cavernous sinus was described by Baron[1] in 1835. It was not until 1856, when Nélaton[8] reported 2 cases of traumatic origin, that the more common etiology was disclosed. Fracture of the base of the skull with traumatic rupture of the carotid artery into the cavernous sinus produces increasing proptosis and eventual ophthalmoplegia. The primitive trigeminal artery is the earliest communication between the carotid and basilar system.[12] An arteriovenous fistula, or an aneurysm, may originate from this site of origin as the vessel becomes a rudimentary structure.

The popular form of therapy has been extracranial, carotid ligation on the affected side. Successful treatment by repeated, prolonged manual compression of the carotid artery has been reported in a few cases.[2] A surprising number of bilateral carotid ligations have been performed in cases in which unilateral occlusion had failed to reduce the pulsating exophthalmos.[5] Hamby and Gardner[6] reported the first successful intracranial ligation of the internal carotid artery in the treatment of carotid-cavernous fistula. This patient had an ipsilateral common carotid ligation and a subsequent contralateral, common carotid occlusion before a cure resulted.

In this angiographic era, thorough planning of the surgical attack is made possible by first visualizing the communicating channels. Jefferson[7] has shown bilateral filling of the cavernous sinus with a single arteriovenous fistula. Ramos and Mount[11] have demonstrated that the proptosis may be on the side opposite the fistula. A case of rupture of bilateral saccular intracavernous aneurysms was reported by Poppen.[10] The following case illustrates bilateral carotid-cavernous fistulas of traumatic origin. Angiographic demonstration of this condition has not been recorded previously, so far as we are aware. The sequence of treatment was repeatedly dictated by angiography.

CASE REPORT

An 18-year-old Private sustained a head injury in a motorcycle accident on April 5, 1953. He was admitted to U. S. Army Hospital, Fort Bragg, North Carolina in a comatose state with bleeding from the nose and right ear. Shock was treated with whole blood, after which he became restless and combative. A right 6th nerve paralysis was evident and Babinski's sign was positive bilaterally. He remained agitated and disoriented, and on April 13, a prop-

tosis was noted on the right with early chemosis and ophthalmoplegia. At this time a left 6th nerve palsy became apparent. A bruit was auscultated over both eyes, but was more pronounced on the right. Skull films did not demonstrate a fracture.

On April 21, 1953, the patient was transferred to the Neurosurgical Section of U. S. Army Hospital, Camp Gordon, Georgia. Marked right proptosis and chemosis were apparent. Bilateral bruit, early protrusion of the left eye, positive left Babinski, restlessness, confusion and recent loss of weight were noted. A definite thrill was palpated over the right carotid. Compression of the right carotid greatly diminished the bruit. A diagnosis of right carotid-cavernous sinus fistula was made.

The stages of angiography and surgical treatment were as follows:

1. *April 22, 1953.* Bilateral percutaneous angiograms revealed a right carotid cavernous fistula and normal circulation on the left (Fig. 1).

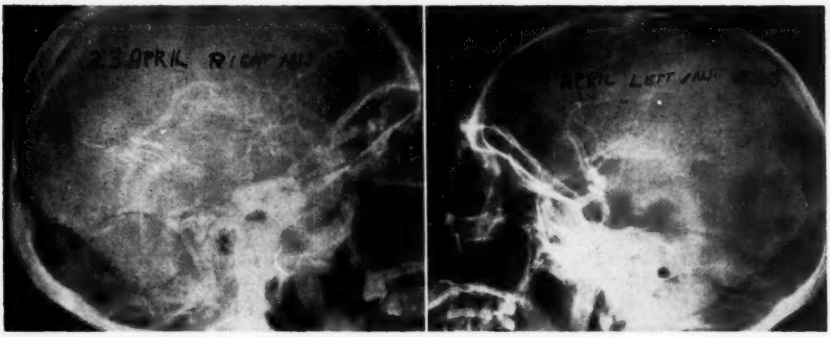

FIG. 1. (*Left*) Right carotid angiogram showing diodrast in the cavernous sinus and dilated ophthalmic veins. (*Right*) Normal left carotid angiogram.

2. *May 4, 1953.* Ligation of the right internal carotid artery was done, with removal of clamp which had been applied 6 days previously and gradually closed. Bruit was markedly diminished on the right side.

3. *May 9, 1953.* Left percutaneous angiography was repeated because of an increase in the bruit over the left eye and the appearance of an easily palpable thrill over the left common carotid artery. Another carotid-cavernous fistula was demonstrated (Fig. 2).

4. *May 12, 1953.* Right frontal craniotomy was done, with supraclinoid clipping of right internal carotid artery. The right bruit became almost inaudible and the left bruit was intensified.

5. *June 22, 1953.* The left internal carotid artery was ligated, with removal of clamp which had been inserted 16 days previously and gradually closed. The left bruit diminished to about 80 per cent of its former intensity. A bruit no longer could be heard on the right.

6. *June 22, 1953.* Open left external carotid angiography was performed because of persistent bruit on left (Fig. 3).

7. *June 22, 1953.* The left common carotid artery was ligated to block flow to external carotid, as the left internal carotid had been occluded previously.

Subsequent Course. Neurological examination at this time revealed that the patient was oriented, rational and alert. He was ambulatory and showed no evidence of hemiparesis, motor incoordination or aphasia. Anesthesia was present over the distribution of the left ophthalmic and maxillary nerves. The left corneal reflex was absent, whereas the right was brisk. The left bruit was still heard but was about 10 per cent of former maximum intensity. A soft murmur continued over the left orbit, but this was inaudible to the patient.

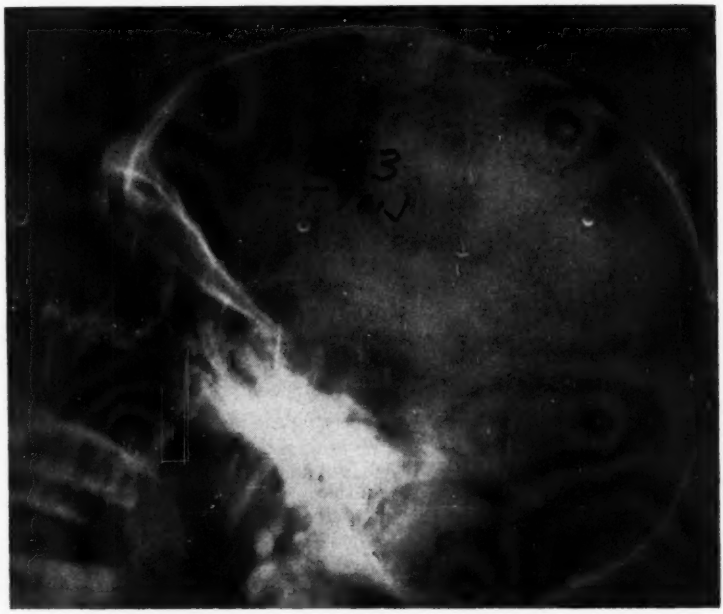

FIG. 2. Left angiogram showing diodrast in left cavernous sinus.

Thirty-two days after occlusion of the left common carotid the bruit disappeared. The proptosis receded completely on each side and the originally described bilateral palsy of the 6th nerve became apparent. Tarsorrhaphy was performed on the right to reduce the chemosis and later on the left because of a keratitis. Lateral closure of the eyelids was maintained temporarily to prevent further ophthalmologic difficulties. The bilateral 6th nerve palsy and above-described anesthesia persist but the patient is otherwise in good health.

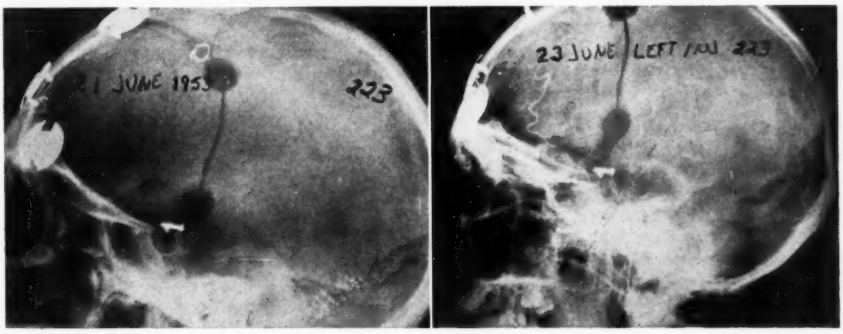

FIG. 3. (*Left*) Lateral radiograph of skull following angiography, for comparison with left external carotid angiogram. (*Right*) Left external carotid angiogram. This shows retrograde filling of the fistula through the ophthalmic artery.

COMMENT

Why the left arteriovenous fistula did not appear radiographically until the right internal carotid artery had been occluded is a matter of speculation. It is felt that the increase in intravascular pressure on the contralateral side, subsequent to initial carotid occlusion, might have been sufficient to burst open a healing intracavernous-carotid tear. Possibly, a vestigial defect in the carotid may have been present to account for the development of the second carotid-cavernous fistula. The reduction in blood flow in the cavernous sinus by right internal carotid trapping and left internal and common carotid ligations eventually produced a thrombosis in the involved channels to close them.

The presence of bilateral carotid-cavernous fistulas may explain the persistence of proptosis in some of the previously recorded cases. Although no general conclusions can be made from a single case report, this may clarify the effectiveness of bilateral carotid ligations in some instances. The demonstration of retrograde filling of the cavernous sinus through the ophthalmic artery, when both internal carotid arteries had been occluded, modified our surgical attack. Mount[9] has also shown evidence of this back flow from the external carotid into the intracranial portion of the internal carotid. Meningeal or pituitary arteries of the external carotid system may also be capable of enhancing this collateral circulation.

SUMMARY

The surgical treatment of a patient with bilateral carotid-cavernous fistulas was dictated by repeated angiographic studies. The demonstration of a second arteriovenous communication on the contralateral side made the changing bruit, shifting carotid thrill, and persistent proptosis understandable. The visualization of retrograde filling of the cavernous sinus through the external carotid system verifies the assumption that potent collateral circulation develops in carotid-cavernous fistulas.

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HERNIATION OF THORACIC INTERVERTEBRAL DISCS WITH SPINAL CORD COMPRESSION IN KYPHOSIS DORSALIS JUVENILIS (SCHEUERMANN'S DISEASE)

CASE REPORT

JOHN H. VAN LANDINGHAM, M.D.*

Service of Neurological Surgery, Neurological Institute, Presbyterian Hospital, New York, New York

(Received for publication January 4, 1954)

Posterior herniations of intervertebral discs in the thoracic region, while not nearly so common as in the lumbar or cervical regions, are a definite and well-recognized clinical entity. As has been described by Logue,[2] these lesions are more apt to declare themselves by clinical evidence of spinal cord compression than by root compression or local back pain. They tend to occur in individuals beyond the age of 30 who show no propensity to generalized disease of the spine. More often than not there is no history of trauma, as emphasized by Logue,[2] and by Love and Kiefer.[3]

The following case of thoracic disc herniation is of interest because of several unusual clinical features which will be pointed out below.

J.J.C., a male aged 17 years, was admitted with a history of having awakened one morning 4 weeks previously with a "numb feeling" (not complete anesthesia) from the hips down. This gradually became more marked and a week later he began to experience awkwardness in walking and a sense of stiffness in the hamstring muscles, starting on the left. There was no history of trauma, pain, sphincter disturbance, or of previous neurological symptoms.

Examination revealed moderate obesity, a moderate dorsal kyphosis with no tenderness of the back, and a wide-based gait, with a suggestion of spasticity and a tendency to slap the toes on the floor when walking. Strength was normal. Position and vibratory perception were slightly impaired in the lower extremities, more so on the right. Touch and pain sensation were present but impaired below the 9th thoracic dermatome. Myotatic reflexes were slightly increased in the lower extremities and there was a bilateral Babinski sign.

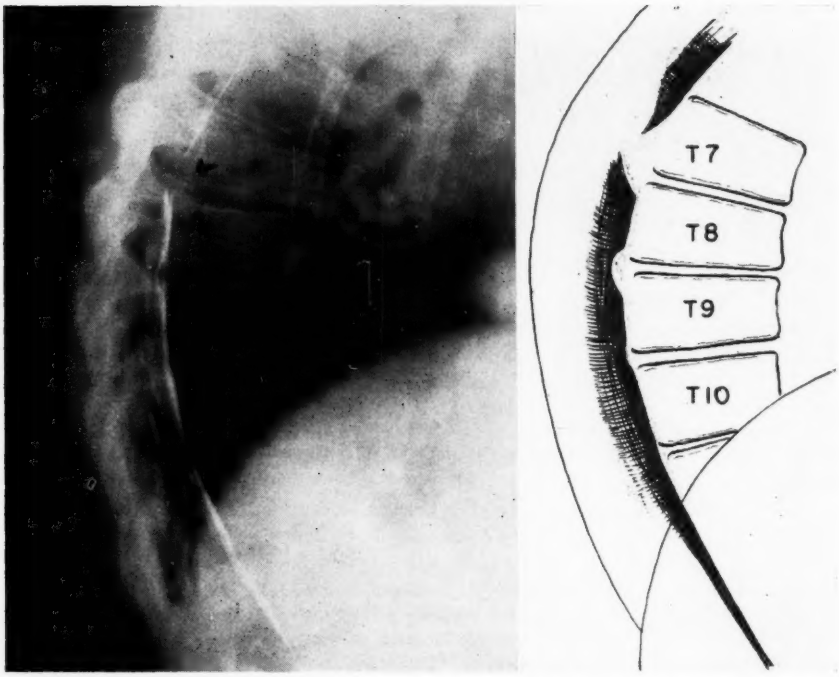
The only significant laboratory finding was a spinal fluid protein of 106 mg. per cent with no manometric block.

X-rays of the dorsal spine showed a kyphotic deformity and some wedging of the mid-thoracic vertebral bodies consistent with Scheuermann's disease. Myelography showed a ventral filling defect at the 7th thoracic interspace with smaller similar deformities at T8 and T9 (Figs. 1 and 2).

Operation. On Jan. 7, 1953, a laminectomy of the 7th, 8th, and 9th thoracic vertebrae revealed two degenerated discs at the 7th and 8th interspaces. These were removed by an extradural approach, but with the dura mater open so that the cord was constantly under direct vision. The spinal cord appeared to be normal in color, size and consistency, but was bowed dorsally. The discs were soft and slightly yellow and had ruptured through the annulus fibrosus but not through the posterior longitudinal ligament. Each disc was removed from the right, following which extradural inspection of the left side revealed no evidence of a ventral mass. After removal of the discs the dorsal bowing of the cord was observed to be greatly reduced and the dura mater was closed.

Course. Postoperatively the patient, fitted with a steel supportive brace for the thoracic spine, improved rapidly. When seen in the follow-up clinic 6 weeks and again 4 months after operation he had no complaints, his gait was normal and the extensor plantar reflexes had

* Present address: Talcott Building, 315 West State Street, Rockford, Illinois.



FIGS. 1 and 2. (*Left*) Pantopaque myelogram showing lateral view of thoracic spine. Note wedging of the vertebral bodies resulting in a moderate kyphosis, and the large ventral defect opposite the T7 interspace and the smaller defects at T8 and T9. (*Right*) Diagram of myelogram.

disappeared. Moreover sensation was intact save for slight hypalgesia on the lateral aspect of each thigh and calf.

COMMENT

This case is of interest for several reasons. First, the patient had physical and x-ray evidence of thoracic spine abnormality typical of Scheuermann's disease. In Scheuermann's[4] report of 18 cases of juvenile kyphosis, there is no mention of spinal cord compression. Cloward and Bucy[1] have reported 10 proved cases of spinal extradural cyst with cord compression. Eight of these were in the thoracic region and associated with either the early or late changes of kyphosis dorsalis juvenilis, and all 8 occurred in the age range from 12 to 20 years. However, so far as can be determined, no other instance of spinal cord compression caused by posterior disc herniation in Scheuermann's disease has been reported in the literature. In this case, moreover, multiple disc herniations were demonstrated by myelography and surgical exploration. To be sure, the large extrusion at the 7th intervertebral space was undoubtedly the only one that produced neurological symptoms and signs. Finally this patient was unusually young for such a lesion. The youngest previously reported patient with thoracic disc herniation of which we are aware was 26 years old, in the series of Love and Kiefer,[3] all others having been over 30.

SUMMARY

A case of spinal cord compression caused by thoracic disc herniation is presented which is of particular interest since it occurred at an unusually young age in the presence of juvenile kyphosis (Scheuermann's disease). The patient's symptoms were relieved by operation.

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Obituary

HOWARD RENNINGER ERB
1914–1953

Howard Renninger Erb died on the 23rd of October, 1953 following a heart attack. He was the son of the late Edward R. Erb, and Mrs. Verda Renninger Erb, and is also survived by his wife, Alice, by four children, Milly, Christine, Hannah and Jonathan Howard, and by a brother, Edward, of East Greenville. Dr. Erb was born in Helena, Montana, October 14, 1914. His preliminary schooling was accomplished in the Allentown High School, Allentown, Pennsylvania from 1929 to 1932. He received his Bachelor of Science degree from Pennsylvania State College in 1936 and his Doctor of Medicine degree from the University of Pennsylvania in 1940 together with his wife, the former Alice Robertson of Swarthmore. After serving a two-year rotating internship in the Philadelphia General Hospital, he entered the Air Force Medical Corps in 1942 and served with distinction in England and Europe and was discharged in 1946 with the rank of major. He went directly to the Mayo Foundation in April 1946 for a Fellowship in Neurosurgery. While there he impressed both his contemporaries and his seniors with the superior nature of his work and all who knew him were affected by his magnificent personality.

Dr. Erb completed his Fellowship at Rochester in 1949, earning the Master of Science degree in Neurosurgery in completing an excellent thesis concerning tumors of the midbrain. He then returned to Allentown and opened an office serving Allentown, Bethlehem, and the entire Lehigh Valley. Dr. Erb was chief of the Neurosurgical Division of the Department of Surgery at St. Luke's Hospital in Bethlehem. He also was Consultant in Neurosurgery at the Allentown General Hospital, the Sacred Heart Hospital, Allentown, the Easton Hospital, Easton, and the Quakertown Hospital. He was a member of the Society of Friends, The Royal Society of Medicine (England), the American Academy of Neurology, The Philadelphia Neurological Society, The Congress of Neurological Surgeons, The Harvey Cushing Society and the American College of Surgeons. He was affiliated with the Lehigh County Medical Society, The American Medical Association, The Pennsylvania Medical Society, The Bethlehem Medical Club and the Saucon Valley Country Club.

Those of us who have had the pleasure of visiting Howard at home in Allentown have enjoyed the very warmest of hospitality from Howard and Alice. Making rounds with Howard gave the immediate impression that this was a man loved and respected by every individual in the various hospitals. The responses as Dr. Erb progressed from the front door, to wards, to hospital beds and on through were not the perfunctory recognitions of an attending doctor by the staff and patients, but the warm, genuine pleasure at seeing again a greatly admired, respected, and trusted friend.

DWIGHT PARKINSON, M.D.

NOTICES

AMERICAN ELECTROENCEPHALOGRAPHIC SOCIETY

The 8th annual meeting of the American Electroencephalographic Society will take place at the Hotel Claridge, Atlantic City, New Jersey, June 11–13, 1954.

A symposium on "The Rhinencephalon" (its relationship to both clinical electroencephalography and experimental neurophysiology with special reference to its electrical activity in relation to behavior and symptoms) will be held on June 13 from 9:00 a.m.–1:00 p.m. under the Chairmanship of Dr. Robert Schwab.

A special session on Medico-Legal Aspects of Clinical Electroencephalography will be held on June 11 from 8:00 p.m.–10:00 p.m. Moderator will be Dr. A. Earl Walker.

GERMAN SOCIETY OF NEUROSURGERY

The German Society of Neurosurgery has elected as Honorary Members Dr. Percival Bailey, Chicago, Dr. Leopold Schönbauer, Vienna, and Dr. Robert Wartenberg, San Francisco.

HARVEY CUSHING SOCIETY

The 22nd annual meeting of the Harvey Cushing Society was held in Santa Fe, New Mexico, May 6–8, 1954. The following officers were elected: President-Elect, Dr. Frederic Schreiber, Detroit; Vice-President, Dr. Richard U. Light, Kalamazoo; Secretary-Treasurer, Dr. David L. Reeves, Santa Barbara. Dr. Edgar Kahn was elected member of the Executive Committee. President of the Society from 1954–1955 is Dr. Harry Wilkins, Oklahoma City. Members of the Executive Committee are: Dr. Frank Turnbull, Vancouver, Dr. Eben Alexander, Jr., Winston-Salem, Dr. Paul C. Bucy, Chicago, Dr. William J. German, New Haven, and Dr. Edgar A. Kahn, Ann Arbor. Mrs. William A. Nosik, Cleveland, was reappointed President of the Ladies Auxiliary, and Mrs. Howard A. Brown, San Francisco, was appointed President-Elect.

NEUROSURGICAL SOCIETY OF AMERICA

The 7th annual meeting of the Neurosurgical Society of America will be held at Grand Hotel, Mackinac Island, Michigan, July 21–24, 1954.

"GANGLIOLYSIS" FOR THE SURGICAL TREATMENT OF TRIGEMINAL NEURALGIA

A. STENDER, M.D.

Clinic for Neurology and Neurosurgery, Free University at the Westend-Hospital, Berlin, Germany

(Received for publication February 1, 1954)

In 1952 Taarnhøj[10] described a method of decompression of the trigeminal nerve for the treatment of tic douloureux. In this procedure the dural sheath enclosing the trigeminal nerve is divided without sectioning the nerve. The dural incision is made over the most posterior part of the ganglion, and follows the course of the trigeminal root until the superior margin of the petrous bone has been reached and the superior petrosal sinus has been divided. It is then usually extended to the tentorium. The operation leaves no sensory deficit.

In Taarnhøj's opinion neuralgia is caused by narrowing of the porus trigemini and chronic pressure, especially in older people. All of his 10 patients were free from attacks from 1 to 8 months after operation. His findings were confirmed by Kautzky[4] who had similar results in 16 cases. A purely mechanical explanation of the results of Taarnhøj's operation, however, would seem unsatisfactory. There is no reason to assume that anatomical narrowing takes place in the trigeminal canal or in other foramina through which cranial nerves pass. Furthermore, trigeminal neuralgia occurs in attacks while a compression would be more likely to lead to continuous pain rather than to paroxysms which can be precipitated by a great variety of external factors, such as variations in temperature as well as by eating, shaving, talking, or brushing of the teeth.

In an unpublished case at Foerster's clinic in Breslau, a Frazier operation for tic douloureux was started but could not be finished because of severe hemorrhage necessitating tamponade and closure before the root could be sectioned. This patient recovered and was surprisingly free of attacks of pain for several years without sensory deficit. With this case in mind an attempt was made to modify Taarnhøj's method by simply exposing the gasserian ganglion without splitting the dura mater or sectioning the nerve.

TECHNIC

The procedure is started, as in Frazier's operation, by an extradural approach after occluding the middle meningeal artery in the foramen spinosum and by blunt dissection of the dura mater from the 3rd branch. After the ganglion has been visualized the 2nd branch is similarly exposed until finally the root itself can be seen (Fig. 1). At this stage the coverings of the cavum Meckelii still overlie the ganglion. This tenuous membrane is occasionally torn by manipulation of the dura mater but usually it is necessary to remove it after an incision with a small hook knife. In re-

moving the dura mater, one should be extremely careful, as traumatization of the ganglion as well as of the pars triangularis of the root may lead to a sensory deficit.

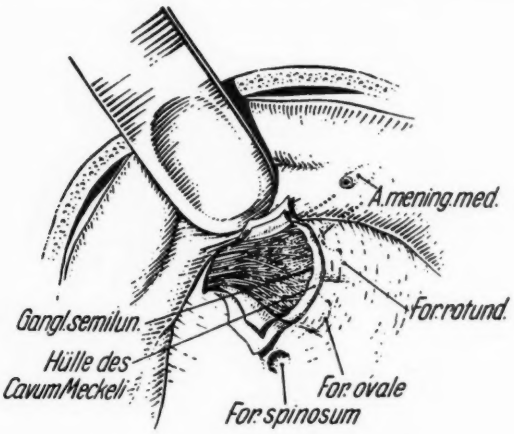

FIG. 1. Exposure of the gasserian ganglion.

CLINICAL MATERIAL AND RESULTS

The gasserian ganglion was exposed in 18 cases during the past 13 months, and in most instances the cavum Meckelii was opened. Of the 18 patients, 16 had typical tic douloureux, 1 sustained trigeminal pain following an inflammatory process in the maxillary sinus, and 1 presented a mixture of continuous pain with additional paroxysmal attacks of pain superimposed. In all cases of uncomplicated tic douloureux, pain was abolished for up to 13 months. In 1 of the earlier cases in which the cavum Meckelii had not been opened, some paresthesias occasionally recurred in the distribution of the 2nd and 3rd branches. A relapse of pain occurred in the patient in whom tic douloureux was complicated by continuous pain, and in this case also the cavum Meckelii had not been opened. Therefore in subsequent cases the opening of the cavum was considered to be the most important part of the procedure. In 2 additional cases there was moderate hypesthesia postoperatively in the distribution of the 2nd and 3rd branches, probably as the result of traumatization of the ganglion.

DISCUSSION

An attempt should be made to discuss the etiology of the paroxysmal attacks of pain in tic douloureux. Several older authors believed that the attacks were caused by a vasomotor disorder, especially angiospasm (Quincke, Kulenkampff,[5] Haertel, Hughes[3]). Others like Olivecrona,[7,8] and Dandy[1,2] were inclined to explain them on a mechanical basis, such as irritation of the root by vascular malformations in the posterior fossa. In some cases of verified cerebellopontine-angle tumors tic douloureux is a symptom.[8] Lewey[6] regarded trigeminal neuralgia as a partial thalamic syndrome. Schaltenbrand[9]

recently described autopsy findings in a case of unilateral trigeminal neuralgia in which both gasserian ganglia showed severe arteriosclerotic changes. In this case no local treatment by alcohol or novocain injections had been performed. On the basis of these findings Schaltenbrand considered trigeminal neuralgia as "claudicatio intermittens" of the gasserian ganglion. This explanation, however, does not seem fully satisfactory, as trigeminal neuralgia may occur in younger or middle-aged individuals.

One might consider an old theory according to which tic douloureux is somehow related to the numerous inflammatory processes of teeth and sinuses. Almost every one has suffered some of these many times in his life. This does not mean that a given inflammatory process as such could produce trigeminal neuralgia. Another interpretation seems justifiable: In all these infectious processes, pain, i.e. irritation of a branch of the trigeminal nerve, is produced. Each attack of pain, according to the theories of Leriche and others, leads to contractions of the blood vessels of the nerve. As many patients suffer from these inflammatory processes repeatedly one could conceive that a "summation of stimuli" in certain cases leads to conditioned vascular reflexes, thus creating a new disease, namely neuralgia. Neuralgia follows its own course and is no longer immediately related to the original episodes of pain which have subsided long ago. In patients with causalgia and in others with the thalamic syndrome tactile stimuli are perceived as pain. One might be justified in speculating that on the basis of irritative stimuli in the distribution of the trigeminal nerve, repeated off and on for 10 or 20 years, a similar mechanism is produced, which leads to precipitation of attacks of pain by physiologically tactile stimuli, such as touching the skin, shaving, touching the gingiva in brushing the teeth, etc.* In this situation of lowered threshold for pain tactile stimuli lead to a paroxysm of pain associated with a "spastic vascular crisis." The single episode of tic douloureux could then be conceived as an acute state of anoxemia. This in turn leads to compensatory mechanisms, usually effective in a short time, with the well known signs of vasodilator activity, as hyperemia of the skin in the area involved, increase in secretion of the nasal mucosa and tearing.

If the paroxysm of pain is associated with a vasomotor reflex mechanism it is also conceivable that arteriosclerotic mechanisms may play a part, as in Schaltenbrand's[9] case. There is a definite increase in incidence of neuralgia with increasing age.

There is one other form of true neuralgia with similarly unbearable attacks of pain: glossopharyngeal neuralgia. On the basis of what has just been discussed concerning trigeminal neuralgia it is quite conceivable that recurrent inflammatory states of the tonsils in certain patients may lead to glossopharyngeal neuralgia. Again by summation of stimuli and progressive conditioning a pathological vasomotor reflex of the 9th cranial nerve might be produced.

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* The extreme rarity of tic douloureux involving the 1st branch would indirectly support the theory that neuralgia is somehow a secondary disease following repeated attacks of dental pain.

If one assumes this mechanism to be valid the operative results initially described might be understood. By exposing the ganglion, its vasomotor supply and that of the branches of the trigeminal nerve would be altered. The operation leads to hyperemia and possibly also edema. In the subsequent stage of reparation new formation of capillaries in the region of the ganglion and its coverings should lead eventually to a different vasomotor situation with improved blood supply, and the spastic vascular reflexes might conceivably cease for this reason. This in turn might lead to cessation of the neuralgia.

Time has been too short for a final evaluation of the therapeutic results of this method. It will be necessary to wait for relapses, and to compare the incidence of relapses with that after other operative procedures. The advantages of this method in comparison with Taarnhøj's procedure are: the surgical risk is smaller, the operation is less extensive, and complications such as extraocular muscle palsies are not encountered. Mainly the method does not lead to the very annoying sensory deficit that follows section of the root.

SUMMARY

Trigeminal neuralgia has been abolished in 18 cases by operative exposure of the gasserian ganglion. In most instances the cavum Meckelii was opened. This seems to be the most important step of the operation. Root section is not necessary with this method, and therefore there is no sensory deficit. One might describe the method as "gangliolysis." So far only patients with genuine tic douloureux have been benefited by the operation.

An attempt is made to explain the paroxysms of pain on the basis of a faulty conditioned vasomotor reflex, leading to paroxysmal anemia. The effect of the operation consists in a fundamental change in the blood supply and vasomotor situation of the ganglion.

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ANGIOGRAPHIC CONFIRMATION OF LATERAL VENTRICLE MENINGIOMAS

A REPORT OF FIVE CASES*

YUN SHANG HUANG, M.D.,† AND CHISATO ARAKI, M.D.‡
1st Surgical Division, Kyoto University Medical School, Kyoto, Japan

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BASED on the study of a meningioma in the posterior horn of the right lateral ventricle and referring to similar tumors reported by Hosoi and by Roscher, De Busscher[5] in 1935 called attention to the occurrence of intraventricular meningiomas and stated ". . . auf diese Weise vielleicht auch ein charakteristisches klinisches Bild herausarbeiten zu können, das eine sichere Lokaldiagnose intra vitam gestattet." Dandy[3] in 1933 was of the opinion that there was no clinical syndrome by which enucleable tumors within the lateral ventricle of the brain (2 of the 13 tumors in his series were pure fibromata) could be diagnosed with sufficient accuracy. Later in 1938, Gardner and Turner[9] likewise expressed their view that the recognition of primary benign intraventricular tumors by clinical means was practically impossible. Cushing and Eisenhardt[2] grouped the symptoms of lateral tumors of the velum under five headings, but symptoms of a tumor of the lateral ventricle do not necessarily correspond therewith. A review of their cases and those reported by Lynn-Thomas,[11] Tschernyscheff,[18] Petit-Dutaillis and Bertrand,[14] Fincher,[8] David *et al.*[4] and Busch[1] will demonstrate how difficult it is to make a correct diagnosis of a meningioma of the lateral ventricle merely by neurological examination. This was true of the five cases previously published by one of us.[10] The additional five cases to be described here also illustrate that symptoms of the tumor under consideration may be manifold, confusing and misleading.

Dandy[3] was of the firm belief that such tumors could be localized with absolute precision by means of pneumoventriculography. Certainly too much cannot be said in praise of this most valuable contribution of Dandy. Busch[1] also laid stress on pneumoventriculography in establishing the diagnosis. However, it does sometimes happen that a primary tumor of the lateral ventricle can hardly be differentiated by ventriculography from invasive gliomas that protrude into or obliterate the ventricle (cf. Cases 2 and 3 of Gardner and Turner[9] and Cases 1, 2 and 4 of Busch[1]). Even when the presence of a tumor within the lateral ventricle is strongly suspected because

* This paper was read in Japanese by one of us (Huang) at the 12th meeting of the Japanese Neurosurgical Society held in Nagoya, April 8–9, 1954.

† Assistant Neurosurgeon.

‡ Professor of Surgery and Neurosurgery.

of the deformity, displacement and/or obstruction of the ventricle(s) in the pneumoventriculograms, the established diagnosis cannot be more than a topical one. That is to say, positive ventriculographic findings alone cannot enable one to make the histopathological diagnosis that the suspected tumor is definitely a meningioma.

Meningiomas of the lateral ventricle of the brain belong to the category of "benign encapsulated tumors" and, given a correct preoperative diagnosis, total removal of these tumors followed by practically complete cure of the patients can be expected. It is supposed that the difficulties of diagnosis and unfamiliarity with the lesion were largely responsible for the unfavorable results (Busch[1]). It is therefore of great importance to try to establish some criteria, or pathognomonic signs, by which the diagnosis of this favorable surgical lesion may be unmistakable. For this purpose we presumed that angiography might give some clues. Thus, carotid angiography has been carried out in patients in whom a lateral ventricle tumor was more or less suspected clinically. In this way such a tumor was uncovered in 5 cases, a report of which with special reference to the angiographic findings is given below.

Case 1. Y. Izuka, a 27-year-old woman, entered the hospital July 24, 1953, complaining of diffuse headaches, occasionally associated with nausea, for some 14 months. The headaches at first were intermittent and unendurably severe, but later became rather continuous and less severe. They were slightly more pronounced on the left side.

Examination. The only positive neurological findings were signs of increased intracranial pressure, viz., choking of the optic discs (2 D. on the right and 4 D. on the left) and marked increase in the spinal fluid pressure (350 mm. of water).

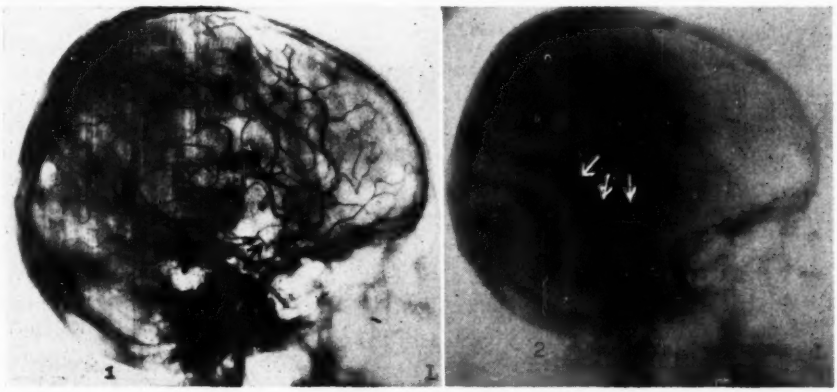
Moljodol (lipiodol) ventriculography was done. The right lateral ventricle was punctured and 4 cc. of contrast material were injected into the posterior horn. The needle failed to get in the left lateral ventricle but at a depth of about 4 cm. it met with a firm creaky resistance. Fluoroscopic examination showed that the contrast material introduced into the right lateral ventricle passed through the foramen of Monro into the 3rd ventricle but not into the opposite (left) lateral ventricle. The ventriculograms disclosed considerable dilatation of the right lateral and the 3rd ventricle; the latter was displaced to the right, more in its upper part, but the former was normal in location.

Angiographic Study (July 31). An intraventricular tumor of the lateral ventricle was suspected, most likely a meningioma (because of the seat of the tumor on the left side and the creaky firm resistance on puncture). Percutaneous carotid angiography was done. Two injections of 35 per cent Uriodone (20 cc. each) were given: the 1st for A-P view and the 2nd for serial profile pictures; both the arteriogram and the phlebogram of either the 1st phase or the 2nd phase.

In the A-P film, the left anterior cerebral artery was shifted to the right, forming an arc with its concavity to the left. Arteries of the Sylvian group were nearly normal in location although there was an area of moderate hypervascularization in the region where the temporal horn should normally be located.

The first profile arteriogram (Fig. 1) showed that the pericallosal and callosomarginal arteries were elevated and parallel but not actually deformed, and the more

peripheral branches were generally stretched or "spinnenbeinartig" (Moniz), indicating a pronounced hydrocephalus. The Sylvian group was pushed forward and upward, and under it were found a fine vascular network and twisted small vessels derived from the enlarged and elongated anterior choroidal artery. The posterior communicating and the posterior cerebral arteries were demonstrated but they appeared to be almost normal in course. The external carotid artery and its branches were not visualized.



FIGS. 1 and 2. *Case 1.* The arteriogram shows a fine vascular network and twisted small vessels derived from the elongated and somewhat enlarged anterior choroidal artery (arrow), while in the phlebogram there is a rather well circumscribed, round and homogeneous overshadowing, in which Galen's ampulla and vein (arrows) were seen to be semicircularly depressed (this is hardly identifiable in this figure because of the overlap of the tumor shadow on Galen's ampulla and vein). Dots are iodized oil drops previously injected for ventriculography.

In the phlebogram (Fig. 2) there was a rather well circumscribed, round and homogeneous overshadowing caused by accumulation of the contrast material. It was as large as a mandarin orange and located in the region of the vascular network described above. Galen's ampulla and vein were semicircularly depressed, but they are indistinct in Fig. 2 because of the overlap of the tumor-shadow.

The most probable angiographic diagnosis was a choroid plexus meningioma, for (1) the nutritional vessel of this apparently hypervascularized tumor was the anterior choroidal artery, (2) the phlebogram was fairly typical for a meningioma, and (3) the tumor was located on the left side.

Operation (August 4). A left temporal craniotomy was made. When the bone flap was reflected, the dura mater was felt to be considerably distended. Exploratory puncture in the central area of the brain exposed met with hard resistance at a depth of 3 cm. Another puncture, presumably at the tip of the temporal lobe, yielded some 50 cc. of watery clear fluid under remarkably increased pressure. After this the dura mater collapsed so that it could be opened readily without hazardous prolapse of brain. A deep incision in the temporal lobe disclosed an encapsulated, very hard and nodular tumor which was soon found to be lying in the ventricle. A finger was passed under the tumor, and with gradual and gentle manipulations the tumor was delivered extracerebrally without any troublesome bleeding. It was then found to receive its blood supply from a large vascular stalk that was continuous with the

choroid plexus. Having doubly clipped and cut off this artery, the tumor was removed in one mass.

Course. Twenty-four hours after operation there were complete motor aphasia and right motor hemiparesis but the general condition of the patient was excellent. The symptoms improved gradually in the course of about 3 weeks and she became entirely well in the 6th postoperative week, when she was discharged (September 18).

Pathological Report. Grossly the tumor measured 6 by 4 by 3.5 cm. and weighed about 100 gm. (Fig. 3). It was covered by a thin glistening capsule and was irregularly nodular. At one point a conglomerate of vessels resembling the choroid plexus was attached. Section of the tumor revealed partly granular and partly fibrous tissue, which was generally gray-white but in some parts tinged with blood. Microscopically, the tumor was a meningioma (transitional meningothelial and fibroblastic). No psammoma particles were found.

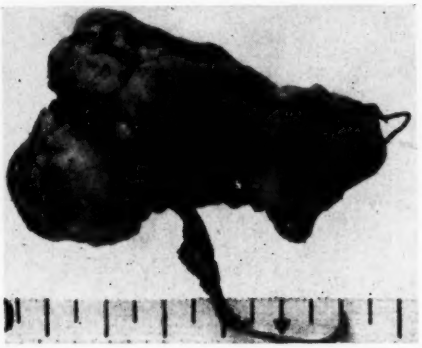


FIG. 3. *Case 1.* Choroid plexus meningioma removed from the left lateral ventricle.

Case 2. Y. Sakata, a 24-year-old woman, was admitted on Sept. 24, 1953. She had been hospitalized twice, under a diagnosis of schizophrenia, in a provincial lunatic asylum during the years 1950–1952, and underwent bilateral prefrontal lobotomy on July 10, 1952. After the lobotomy all the symptoms attributed to schizophrenia seemed to have disappeared but gradually she began to have headaches associated with projectile vomiting. One year after the lobotomy, i.e. 1½ months prior to admission, generalized seizure with loss of consciousness occurred. Recently impairment of vision and memory were noted.

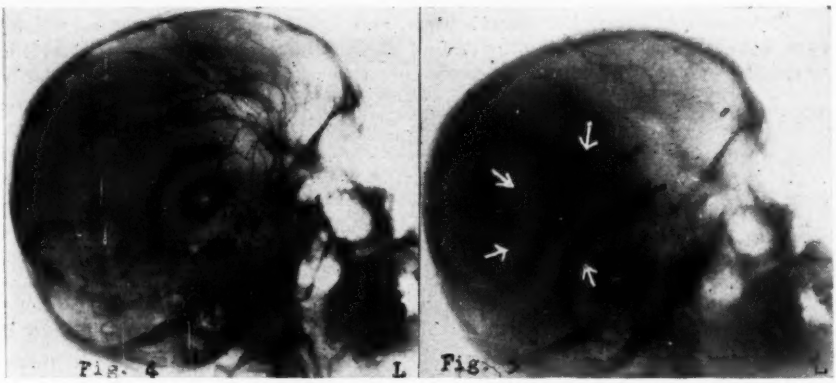
Examination. The patient was somewhat impassive, but not actually torpid. She was cooperative, though she answered questions very slowly. She was disoriented as to the surroundings and the time. Her memory was markedly reduced. The optic disc was choked bilaterally, showing an elevation of 2 D. and postneuritic atrophy. Visual acuity was reduced to perception of gross finger movements in front of the eyes. Corneal reflex was very sluggish on the left side. Hearing was normal on either side and caloric nystagmus was present. The tongue was slightly but definitely deviated to the right on protrusion. Tendon reflexes were all hyperactive but clonus or abnormal reflexes were absent. Motor or sensory weakness, speech disturbances and hemianoptic defect in visual fields were all absent. The spinal fluid was under increased pressure (350 mm. of water) but clear and without any discoloration.

Roentgenograms of the skull revealed two burr holes made at the previous prefrontal lobotomy and a homogeneous shadow as large as an apple, suggestive of a calcified mass, in the temporal region.

At Moljodol-ventriculography, puncture of the left posterior horn was unsuccessful so that the contrast medium was introduced into the right side only. The pictures disclosed that the foramen of Monro on the left side was completely obstructed so that the oil could not pass into the left lateral ventricle, but the passage of the oil into the 3rd ventricle was undisturbed. Both the right lateral and the 3rd

ventricle were markedly dilated. The former was normal in location but the latter was displaced to the right, its anterior part being farthest from the midline.

Carotid angiography (October 6) was performed on the left side, a tumor of the left lateral ventricle being suspected. The arteriogram (Fig. 4) showed that the siphon was stretched and lifted high up. The Sylvian arteries were also markedly elevated and to some degree displaced forwards, forming a large semicircle with its concavity downward. Inside this concavity there was a well delimited, hypervascu-



FIGS. 4 and 5. *Case 2.* In the arteriogram a well delimited, hypervascularized, oval and more densely shadowed area is seen in which the elongated and enlarged anterior choroidal artery (arrow) runs and terminates in a fine vascular network. In the phlebogram this area still remains as an overshadowing (arrows) because of the accumulation of contrast material. Dots are Moljodol drops.

larized, oval and more densely shadowed area, the size of an apple, in which the anterior choroidal artery was found to run and terminate in a fine vascular network. In this area, however, no arteriovenous anastomosis was seen (dots are drops of oil used for ventriculography). Branches of the anterior cerebral artery, including the pericallosal and the callosomarginal arteries were in general stretched and arranged, more or less, in parallel rows, indicating an outstanding hydrocephalus. In this picture, tributaries of the external carotid artery were also demonstrated but there was no evidence that they were anastomosed with the internal carotid tributaries, nor that they were connected with the (tumor-) shadow. In the phlebogram (Fig. 5) ascending cerebral veins were about to disappear but an oval shadow caused by accumulation of the contrast material still remained, corresponding to the hypervascularized area seen in Fig. 4. (The A-P film revealed only obscure vascular shadows so that it was of little diagnostic value.) In analyzing these angiographic findings, it was concluded that the lesion must be a meningioma of the lateral ventricle.

Operation (October 9). An extensive temporo-parieto-occipital craniotomy was done. The dura mater was felt to be surprisingly distended on puncture with an exploratory needle at various points. Thus, a hard resistance was felt at a depth of 1 to 3 cm. Incision of the dura mater in the temporal region and of the underlying brain substance was followed by spontaneous prolapse of a part of the tumor, which was granulated and covered with a thin capsule, brown to dark red in color and firm as elastic in consistency. By guy sutures the tumor was gently and gradually pulled out extracerebrally, when several vascular stalks of varying size were seen to be

attached to its capsule. These vessels were cut off after clipping or cauterization and the tumor was removed in one block. Immediately after the extirpation there was profuse bleeding from inside the ventricle, which was controlled by application of gelatine sponge. It was not possible to confirm whether the tumor had any connection with the choroidal plexus or not, but a large part of the tumor had certainly occupied the left temporal horn and trigonum, adhering in no part to the ventricular wall but to the region of the glomus. The gelatine sponge was left in place, because hemostasis was otherwise impossible, and the wound was closed as usual.

Postoperative Course. For about a week there were intermittent fever, sometimes even hyperthermia, and bleeding out of the drainage tube left inserted in the ventricle. Although she was not actually comatose, she could not answer because of motor aphasia apparently resulting from the operation. All these symptoms, however, progressively improved in the following fortnight. Four weeks after operation, temperature was normal and the optic discs were flat. There were no neurological abnormalities, except that she still appeared somewhat depressed and her visual acuity was not preserved normally. She was discharged 6 weeks after operation on November 27.

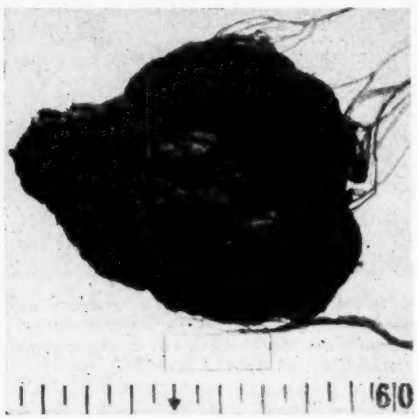


FIG. 6. *Case 2.* Meningioma of left lateral ventricle.

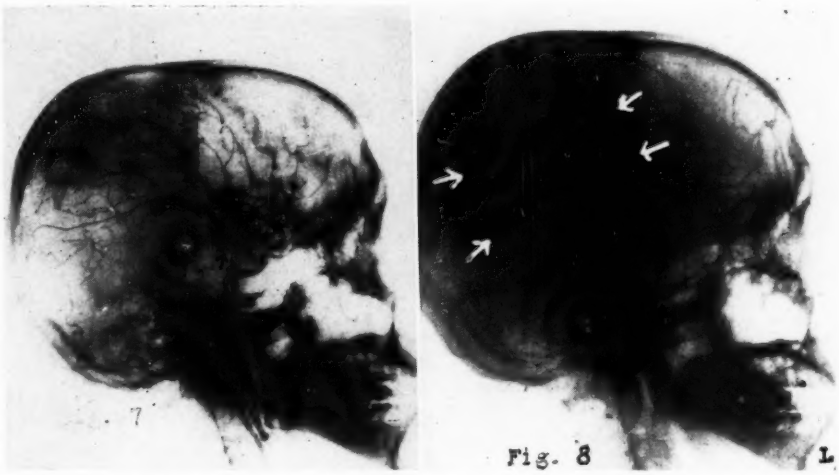
Pathological Notes. The tumor (Fig. 6) was 8 by 6 by 5.5 cm. in size and 165 gm. in weight. It was granular and encapsulated, dark red in color and rather hard in consistency. There was a furrow on which were found several small-sized vascular stalks and plexus-like conglomerates of vessels. The cut surface appeared homogeneously granular and reddish-gray, and was as hard as elastic on palpation. Microscopically the tumor was a meningothelial meningioma with whorl formation.

Case 3. H. Mizuguchi, a man aged 28, entered the hospital on Oct. 13, 1953, complaining of diffuse and severe headaches of 2 years' duration. For the last 6 months the headaches had often been accompanied by vomiting and there developed sensory paresis of the right arm and leg, dizziness and double vision.

Examination. The optic discs were blurred (incipient papilledema) and there was slight ptosis of the right upper eyelid. Visual acuity was apparently not reduced but a complete right homonymous hemianopia was present. There was slight motor hemiparesis with marked hemihypesthesia, including loss of deep sensibility, on the right side. Deep and superficial reflexes were equally exaggerated on both sides. In addition, apraxia and alexia were present (the patient was right-handed). Lumbar puncture revealed an increased spinal fluid pressure, 300 mm. of water. Psychiatrical examination disclosed an obvious weakness in memory but no other frontal syndrome.

Carotid angiography (October 19) was made on the left side. In the A-P film, an arched displacement to the right of the left anterior cerebral artery was seen. In the

lateral arteriogram (Fig. 7), the anterior cerebral artery and its branches were generally stretched and arranged rather vertically in nearly parallel rows. The carotid siphon was somewhat compressed at the lower half, but it was stretched at the upper half. The proximal portions of the Sylvian arteries were slightly elevated and the two upper branches (posterior parietal and angular arteries) were so markedly dislocated upwards and forwards that they ran more perpendicularly than usual. But the lowest branch (posterior temporal) was, on the other hand, slightly depressed distally. These findings indicated a large tumor in the parieto-occipito-temporal region,



FIGS. 7 and 8. *Case 3.* In the arteriogram the choroidal artery (arrows), elongated but of a very fine calibre, is seen to take part in formation of the vascular network in the parieto-occipital region, while in the phlebogram a large, round and well circumscribed overshadowing (arrows) is visualized in the same region. The latter findings were, however, overlooked before operation because we were preoccupied by the idea that the lesion must be an infiltrating glioma.

where a spiderweb-like vascular network was formed seemingly by the Sylvian arteries. Arteriovenous anastomosis or dots were not present. The external carotid tributaries were also visible in this picture, but there was no anastomosis between these and the internal carotid branches. The anterior choroidal artery, tortuously elongated but of very fine calibre, was overlooked and the phlebographic findings were at that time thought to be quite normal. (This misreading will be commented upon below.) A preoperative diagnosis of astrocytoma (or an infiltrating glioma) in the left parieto-occipito-temporal region was made.

Operation (October 23). A left osteoplastic craniotomy was performed. When the dura mater was incised some 3 cm. in length, the tense brain was about to bulge out. There was widening of the gyri but no abnormal discoloration of the cortex. Upon exploration with a biopsy cannula, a hard resistance was encountered at a depth of 3 cm. The cortex was incised, disclosing an encapsulated, dark red and fleshy subcortical tumor, the surface of which was densely covered with fine vascular networks. The tumor seemed to be firmly fixed in the brain substance, and any manipulation to dislodge and remove it ensued in critical bleeding from its surface. Accordingly,

after electrosurgical excision of some biopsy pieces and control of the resultant bleeding, the wound was closed.

Postoperative Course. The temperature was as high as 40°C. for the first 3 days. The hyperthermia subsided for a couple of days thereafter only to reappear and the patient succumbed in coma on the 8th postoperative day.

Autopsy (October 31) was limited to the brain. An encapsulated hard tumor, the size of a man's fist and dark red in color, filled the posterior half of the lateral ventricle including the temporal horn (Fig. 9). The ventricle was studded with clots,

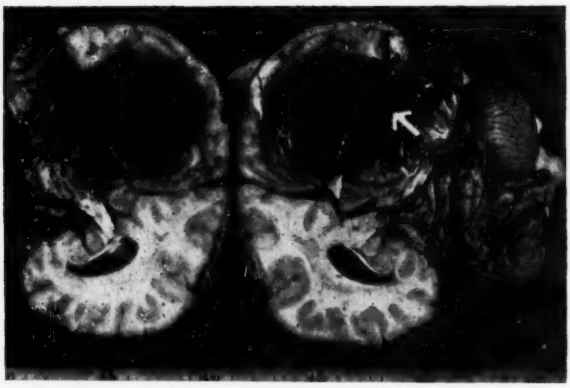


FIG. 9. *Case 3.* An intraventricular meningioma of the left lateral ventricle. Note attachment (arrows) of the choroid plexus and glomus to the tumor.

unquestionably caused by the operation. The tumor could readily be shelled out of the ventricle save for several vascular stalks which were mostly continuous to the choroid plexus and glomus. The tumor measured 6 by 5.5 by 5.5 cm. and weighed 132 gm. The cut surface was generally reddish-gray in color and there were scattered numerous small hemorrhagic foci and a more centrally placed necrotic area.

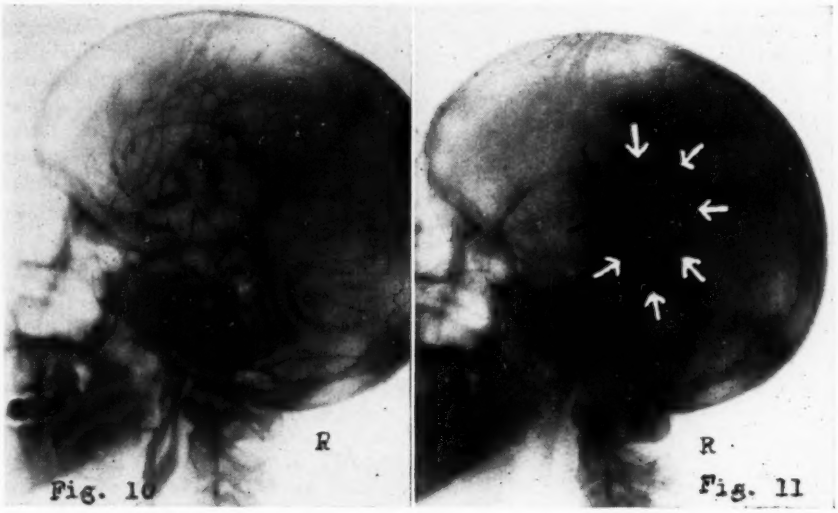
Histopathologic examination showed that the tumor tissue was largely a meningothelial meningioma with whorl formation, but partly a hemangioblastic meningioma.

Comment. On reviewing the angiographic pictures now, the anterior choroidal artery is definitely seen to be elongated, though of very fine calibre and connected with the spiderweb-like network (Fig. 7), while a large, round and well circumscribed overshadowing is visible in the phlebogram (Fig. 8). The oversight, or unwariness, of these findings seems to have resulted obviously from our preoccupation by the idea that the lesion must be an infiltrating glioma.

Case 4. Y. Takahashi, a 27-year-old woman, was admitted on Oct. 13, 1953. For 6 months she had been suffering from headaches, intermittent and diffuse but tending to be somewhat more pronounced in the frontal region bilaterally. When she overworked or was fatigued, nausea and vomiting often occurred. In the last few months blurring of the vision was noticed.

Examination. Positive neurological findings were: choked optic discs, 3 D. on the right and 4 D. on the left, and cerebrospinal hypertension (370 mm. of water) with xanthochromic discoloration of the fluid. There seemed to be a questionable tactile hypesthesia of the two ulnar fingers and the ulnar half of the hand on the left side.

Carotid angiography (October 19) was performed on the right side. First, the A-P view was taken. This showed slight but definite arched displacement to the left of the right anterior cerebral artery, with the concavity to the right. We then proceeded to take right lateral views. In the arteriogram (Fig. 10), the anterior cerebrals were



FIGS. 10 and 11. *Case 4.* The arteriogram shows the entangled vascular mass (arrow) which originated exclusively from the anterior choroidal artery. In the phlebogram there is a well circumscribed overshadowing (arrows) in the corresponding region. The depression of Galen's ampulla, which formed the posterocaudal margin of the tumor-shadow, is evident in the original film, but could not be well reproduced.

seen to be stretched out, running rather vertically and in parallel rows. The proximal portions of the Sylvian arteries were pushed upwards, inside the concavity of which was a tangled vascular mass having its origin exclusively from the enlarged and elongated anterior choroidal artery. No arteriovenous anastomosis or dots were evident. The posterior communicating and the posterior cerebral artery were of nearly normal location and form. The external carotid tributaries were visible too, but any connection between these and the internals was not present. In the phlebogram (Fig. 11) there was a well delimited overshadowing, as large as a big walnut, corresponding to the region where the tortuous vascular conglomerate was located in the arteriogram. Galen's ampulla was slightly depressed, forming the posterocaudal margin of that overshadowing. A tumor connected with the anterior choroidal artery, i.e., a meningioma of the choroid plexus on the right side, was our angiographic diagnosis.

Operation (October 30). An osteoplastic craniotomy was made in the right temporoparietal region. The dura mater was under considerable tension and a puncture

through it to a depth of about 3 cm. yielded an accumulation of xanthochromic fluid, which was thought to be cerebrospinal fluid, as on lumbar puncture made at the time of admission the fluid was also yellow-tinged. Incision of the dura mater and the cortex after evacuation of the fluid brought to view an encapsulated dark bluish-red tumor lying in the lateral ventricle. This tumor replaced the temporal horn and extended to the trigonum. The tumor was in no place adherent to the wall of the ventricle but it was connected with a tortuous vascular stalk, i.e., the conglomerated vessels of the choroid plexus, which were greatly dilated. The tumor could readily be removed after doubly clipping and cutting off the vessels.

Postoperative Course. The patient made a complete recovery and was discharged in the 4th postoperative week, on November 28, in a normal and healthy condition.

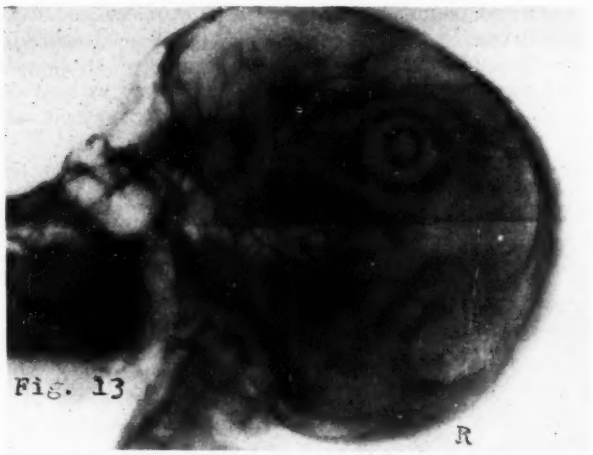
Pathological Note. Grossly, the tumor (Fig. 12) measured 5 by 4.5 by 5 cm. and weighed about 60 gm. The cut surface was granular, reddish-gray and fleshy in appearance. Histopathological study proved the tumor to be a meningothelial meningioma, containing a few psammoma particles.

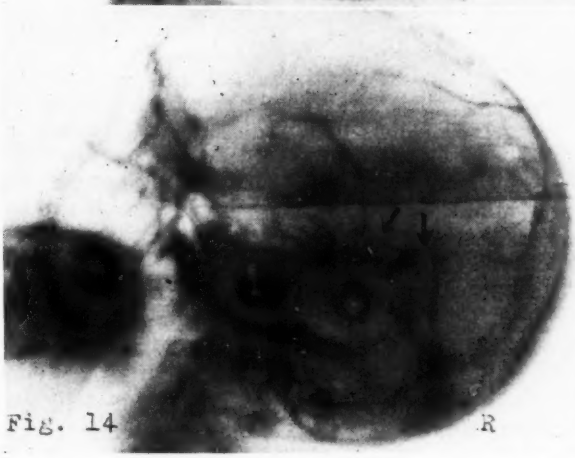
FIG. 12. *Case 4.* Choroid plexus meningioma removed from the right lateral ventricle.

Case 5. H. Umehara, a girl aged 17, was admitted on Jan. 27, 1954, complaining of headaches of 6 months' duration. The headaches had been paroxysmal and diffuse. Two months after onset of the headaches the patient was seen to drag her left foot on walking. Another 2 months later, she had for some time noticed double vision. The disturbance of gait had gradually increased and recently there had developed motor weakness of the left hand and leg. After a lumbar puncture the headaches seemed to have localized mainly in the right frontal region.

Examination. Positive neurological findings were: bilateral choked disc of 3 D.; signs of involvement of the facial, glossopharyngeal, vagal, accessory and hypoglossal nerves, all on the left side and motor in type; left motor hemiparesis; questionable astereognosis on the left side; hyperactivity of all tendon reflexes, slightly more pronounced on the left; and cerebrospinal hypertension (230 mm. of water). The left-sided (pseudo-) ataxia was apparently ascribable to the left motor hemiparesis.

Carotid angiography (January 29) was made on the right side, with the suspicion of a tumor in the right cerebral hemisphere. The A-P picture revealed an arched dislocation of the right anterior cerebral artery to the left side. The lateral angiogram (Fig. 13) showed that the peripheral arteries were generally stretched. Worthy of note was that the anterior choroidal artery was conspicuously enlarged and elongated, but that it did not end in or form any vascular tangles or network. The distal half of the siphon was lifted up and the Sylvian arteries were markedly elevated and somewhat pushed forwards at the proximal halves. The posterior communicating and the posterior cerebral artery were seen to be normal in location and in form. The external carotid arteries (superficial temporal and occipital arteries) appeared





FIGS. 13 and 14. *Case 5.* The arteriogram shows the markedly enlarged and elongated anterior choroidal artery (arrow). Despite this there is no accumulation of the contrast material in the phlebogram. Galen's ampulla and vein are obviously depressed (arrows).

normal. In the phlebogram (Fig. 14), Galen's ampulla and vein were slightly but evidently depressed although an accumulation of the contrast material was not visualized. An astrocytoma of the right temporal lobe was our first preoperative diagnosis. However, a meningioma of the choroid plexus was not entirely excluded, because of the remarkable enlargement and elongation of the anterior choroidal artery in the region of the presumed tumor. Further, on comparing the angiogram with Torkildsen's Fig. 16,[17] an ependymoma of the right temporal lobe was also considered highly probable.

Operation (February 2). A right temporal craniotomy disclosed that the suspected tumor was not a glioma but an encapsulated firm tumor occupying the lateral ventricle in the region extending from the central part to the tip of the temporal

horn, which was tapped, permitting the escape of watery clear fluid. When the tumor was pulled out with ease by guy sutures, it was found to be attached to the choroid plexus only. The choroid plexus was considerably enlarged. It was caught by clips and divided and the smooth-surfaced tumor was removed without difficulty. The wound was closed after the ventricle was filled with physiologic saline solution, which remained crystal-clear.

Postoperative course was uneventful except for a transient motor aphasia. There was gradual improvement in function of the facial and hypoglossal nerves. Choking of the optic discs was hardly noticeable and the headaches disappeared, but the head was still tilted somewhat to the left and the uvula deviated to the left at the time when she was discharged on March 13. Weakness of the left hand persisted and pseudoataxia was residual.

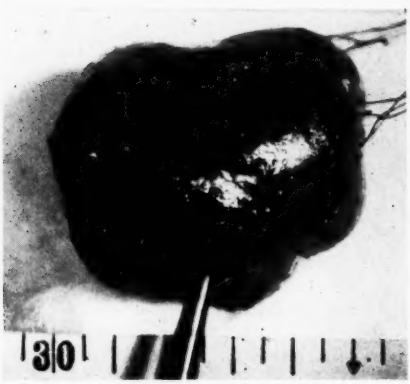


FIG. 15. *Case 5.* Choroid plexus meningioma removed from the right lateral ventricle. Note the vascular stalk, and a tag of normal choroid plexus, picked up by the forceps.

It may be of interest to note that repeated carotid angiography performed 1 month after operation (March 4) revealed that the anterior choroidal artery was no longer demonstrable.

Pathological Note. The tumor (Fig. 15) was spherical, measured 6 by 5 by 4 cm., and weighed 73 gm. The cut surface showed a homogeneously gray-white appearance and was hard on palpation.

Histologically, the tumor was of nearly the same variety as those in the preceding cases, namely, a transitional meningothelial and fibroblastic meningioma with few whorls and no psammoma bodies.

COMMENTS AND CONCLUSIONS

At present the literature is flooded with articles on angiography and its findings. But it is generally believed that, in the diagnosis of an intraventricular tumor, ventriculography is far superior to angiography. In the literature, therefore, there are only a few papers dealing with angiograms of such tumors. However, in view of the fact that meningiomas of the lateral ventricles of the brain originate either from the choroid plexus itself (plexus-meningioma) or from the vascular fringes of the telae (lateral tumors of the velum), it would be quite reasonable to assume that such tumors should have their blood supply entirely or, at least, partly from the choroidal plexus and, consequently, from the anterior choroidal artery. We had on that account supposed that the arteriogram of a meningioma of a lateral ventricle might reveal some changes characteristic of that lesion. Engeset (cited by Monrad-Krohn[13]) was of the opinion that characteristic of meningiomata are one or more conspicuously large afferent vessels in the arteriogram, whilst in the phlebogram there is often a great accumulation of contrast material in the region of the tumor. This view led us to postulate that "one

or more conspicuously large afferent vessels" might be identical with the anterior choroidal artery in the arteriogram of a lateral ventricle meningioma. And since a meningioma of a lateral ventricle differs in no way, either macroscopically or microscopically, from any intracranial meningioma of other localization but for its seat in the ventricle, we further anticipated that the phlebogram of such a tumor might likewise show "a great accumulation of contrast material in the region of the tumor." On such assumptions, the angiograms were obtained and analyzed in the 5 cases reported above. The angiographic findings in those cases are recapitulated and discussed below:

1. *An arched displacement to the contralateral side of the anterior cerebral artery.* Not only when a lateral ventricle meningioma is suspected but also in cases of increased intracranial pressure only, or so-called pseudotumors, as well as in some cases of psychiatric disorder (cf. Case 2 and Lynn-Thomas' case[11]), an angiographic study should always be carried out. As a lateral ventricle meningioma may be devoid of any localizing symptoms (cf. Cases 1 and 2) and occurs at least twice more frequently on the left side than on the right,[10] it is suggested that, in a case in which lateralization is questionable, puncture of the carotid artery should preferably be done first on the left side and that an anteroposterior exposure be made. When the presence of an expanding lesion is undoubtedly shown in this A-P picture, exposures for serial lateral pictures should then be made on the suspected side. Besides an arched dislocation of the anterior cerebral artery, there may be seen an area of hypervascularization corresponding to the region of the tumor (cf. Case 1), but this finding alone, speaking from our experience, is scarcely helpful for the histological diagnosis.

2. *Signs of marked hydrocephalus.* The pericallosal and callosomarginal arteries, if demonstrated, are usually elevated and conspicuously stretched. The more peripheral branches are generally straightened or arranged in rather parallel rows, or they appear "spinnenbeinartig," indicating a hydrocephalus. This sign never fails in case of a ventricle tumor, although it may be present in cases of other intracranial growths.

3. *Displacement and deformation of the surrounding vessels.* This finding alone, or together with the findings described above in items 1 and 2, may actually be present with any kind of intracranial tumor. In fact, it merely indicates the region in which a suspected lesion is situated. Therefore, which arteries undergo deformity and dislocation depends merely on the particular seat of the tumor. However, it should be noted that even in case of a lateral ventricle meningioma, if it involves the adjacent subcortex, the surrounding vessels may take part in formation of a hypervascularized area (cf. Case 3: Fig. 7).

Regarding the phlebogram, Galen's ampulla and vein may be depressed (cf. Cases 1, 4 and 5: Figs. 2, 11 and 14). In consideration of the anatomical relationship, this finding seems to be rather unique for a tumor in the lateral ventricle (Moniz[12] schematically illustrated this in his comprehensive and excellent monograph, in Fig. 162, p. 198). And particularly since plexus-meningiomas appear to arise more often than elsewhere from the region of

the glomus (Cushing and Eisenhardt[2]), depression of Galen's ampulla and vein may be deemed indicative of such tumors.

4. *Enlarged and often elongated anterior choroidal artery which terminates in tortuous vascular tangles or network.* According to Moniz[12] the anterior choroidal artery, when demonstrated in the lateral arteriogram, is thin and 150 mm. long, which has a diagnostic value in exceptional cases. However, in view of the origin of lateral ventricle meningiomas, it is easily understandable that the anterior choroidal artery should become enlarged, often elongated and form, or terminate in, vascular tangles (Cases 1 and 4) and/or network (Cases 1, 2 and 3). For in cases of meningioma, it is rather constantly seen that the afferent, or nutritional, vessel(s) is greatly enlarged and often elongated. And in the case of a lateral ventricle meningioma the afferent vessel is either exclusively or, at least, partly the anterior choroidal artery.

5. *A well circumscribed accumulation of contrast material (overshadowing) in the phlebogram in the region of the tumor*, suggested by items 3 and/or 4. This finding is characteristic of any intracranial meningioma, irrespective of its localization. But, this finding combined with item 4 seems to be pathognomonic for a lateral ventricle meningioma, provided item 6 below is established. In passing, it should be mentioned that no accumulation of the contrast material may be visible in the phlebogram despite the presence of a markedly dilated and elongated anterior choroidal artery (cf. Case 5: Fig. 14). Ethelberg[7] pointed out that there were two angiographic types of meningioma, one in which the tumor was abundantly vascularized, and another in which no conspicuous vascularization could be observed. Case 5 certainly belongs to the latter type of Ethelberg.

6. *No evidence of participation of external carotid in the blood supply of the tumor.* Unlike meningiomas of other common localization, such as parasagittal, convexity, sphenoidal ridge, olfactory groove, and falx, any blood supply to the tumor from the external carotid tributaries, for example from the superficial temporal and/or in particular from the middle meningeal arteries, should not be demonstrated, because the lateral ventricle meningiomas lie either entirely or partly in the ventricle and are not attached to the overlying dura mater. Should there be, therefore, any "external" vascular connection with the tumor in the presence of item 5, the tumor must be a common meningioma with dural attachment rather than one of a lateral ventricle.

Not only do the angiograms serve to establish the correct diagnosis preoperatively, but the lateral arteriograms in particular may also guide the surgeon in treatment of the vessels attached to the tumor while operating, by showing the degree, extent and location of the vascularization of the tumor. For instance, the tumor in Case 3 was so hypervascularized and large in size (Fig. 7) that, in retrospect, it should have been anticipated that total removal was less probable and, consequently, the postoperative prognosis would be worse than in the remaining cases.

We have had no personal experience with carotid angiography in case of a plexus papilloma or an ependymoma in the lateral ventricle. Shimidzu[16]

described his Case XVI as follows: "Der weiche Tumor verstopft den r. Seitenventrikel. Mittlere Partie der A. pericallosa ist stark nach links verschoben. Der Tumor wird hauptsächlich durch A. chorioidea ant. dextra ernährt, die etwas dicker als links erscheint." But the angiograms were not presented in his paper and there was no histopathologic note about that soft tumor.

Torkildsen[17] in the legend of his Figs. 16 and 17, the arteriograms of an ependymoma of the temporal lobe, states that the anterior choroidal artery is abnormally large and appears stretched. In these figures, however, any vascular tangles or network connected with the anterior choroidal artery were not found, and the phlebogram was not shown. Riechert's[15] Fig. 33 is the lateral arteriogram of an ependymoma in the lateral ventricle. In that picture, however, the anterior choroidal artery is not traceable.

Originating from the choroid plexus exclusively and possessed histopathologically of innumerable vessels of varying size in the central core, a choroid plexus papilloma may possibly reveal angiographic findings similar to those of a lateral ventricle meningioma. Future study will make this point clear.

It is astonishing and worthy of note that the lateral ventricle meningiomas met with in our clinic up to the present, totaling 10, constitute approximately 15 per cent of our small series of intracranial meningiomas. Essbach,[6] in 1943, collected from the literature 53 cases of lateral ventricle meningioma. Including our 10 cases, we have been able to find no more than 70 cases of such tumors to date. But, it has become our impression that the lateral ventricle may be regarded as one of the most important seats of predilection for occurrence of meningiomas, on a par with the parasagittal region, the convexity, the sphenoidal ridge, the tuberculum sellae, the olfactory groove and the falx.

SUMMARY

Five cases of lateral ventricle meningioma verified at operation are reported with special reference to the angiographic findings.

It is suggested that an angiographic study should always be carried out not only when a lateral ventricle meningioma is suspected but also in cases of increased intracranial pressure only, or a so-called pseudotumor, as well as in some psychiatric patients. If there are no signs of lateralization, carotid angiography should be made on the left side first and in the anteroposterior direction.

When this A-P picture indicates an arched displacement of the anterior cerebral artery to one side, serial exposures for the lateral views should then be made on the suspected side. The presence of an elongated and often enlarged anterior choroidal artery terminating in vascular tangles and/or network in the region of the probable tumor, indicated by deformity and dislocation of the surrounding arteries in the lateral arteriogram, together with an accumulation of the contrast material (overshadowing) in the corresponding region in the phlebogram, may be considered quite pathogno-

monic for a meningioma of the lateral ventricle. In this case, however, participation of the external carotid in the blood supply of the tumor must be absent. Occasionally, the anterior choroidal artery may be only obscurely demonstrated, while the phlebogram reveals a characteristic overshadowing in the region of the tumor. Conversely, no accumulation of the contrast material may be visible in the phlebogram despite the presence of a markedly dilated and elongated anterior choroidal artery. When the tumor under discussion is considerably large in size or adequate in location, Galen's ampulla and vein may be depressed. Signs of a hydrocephalus are usually very pronounced.

Not only do the angiograms serve to make the correct preoperative diagnosis, but the lateral arteriogram in particular may also guide the surgeon in treatment of the vessels attached to the tumor while operating, and enable him to foretell the operability, or the postoperative prognosis, by showing the degree, extent and location of the vascularization of the tumor.

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NECROSIS OF BRAIN AND SPINAL CORD FOLLOWING X-RAY THERAPY*

N. MALAMUD, M.D., E. B. BOLDREY, M.D., W. K. WELCH, M.D., AND E. J. FADELL, M.D.

Departments of Psychiatry and Neurological Surgery, University of California Hospital, and Letterman Army Hospital, San Francisco, California

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IN RECENT years, a number of reports have appeared in the literature dealing with complications of the central nervous system, frequently fatal, following X-ray therapy for tumors or other lesions within or outside the cranium. Of the cases confirmed by biopsy or postmortem examination, we found 12 of cerebral necrosis (Fischer and Holfelder,[5] Markiewicz,[6] Scholz and Hsü,[10] O'Connell and Brunschwig,[7] Pennybacker and Russell[8]), 4 of brain stem (Boden[1]) and 3 of spinal cord myelitis (Boden,[2] Stevenson and Eckhardt[11]). The practical significance of such undesirable complications is obvious, besides the theoretical considerations concerning the pathogenesis of the effect of X-irradiation. It is for these reasons that we wish to report the clinicopathologic findings in 2 cases.

REPORT OF CASES

Case 1. *History.* S.M., a negro airman, aged 22 years, had been hospitalized on April 22, 1952 because of nasopharyngeal carcinoma which had developed during the previous 4 months and later metastasized to the left posterior cervical lymph nodes. Between the 1st and 20th of May 1952, the patient was given external irradiation. This was directed through three ports, 3300 r (air) being given to the right, 1650 r (air) to the left and 1650 r (air) to the back of the nasopharynx-cervical region, over a period of 20 days (Table 1). The calculated tissue dose in the center of the field was approximately 5000 r. He was then discharged from the hospital and returned to duty. Repeated follow-up examinations during the ensuing year failed to reveal recurrence of tumor.

Readmission. On May 7, 1953, the patient was readmitted because of progressive

TABLE 1

Portal	Area	Field Size	KV	MA	Filter	HVL	TSD	Total Duration r (air)	
#1	L. Nasopharynx-cervical	9×20 cm.	220	15	½ Cu 1A1	1.37 Cu	50 cm.	3300	20 days
#2	R. Nasopharynx-cervial	9×15 cm.	220	15	½ Cu 1A1	1.37 Cu	50 cm.	1650	20 days
#3	L. Occipito-cervical	9×16 cm.	220	15	½ Cu 1A1	1.37 Cu	50 cm.	1650	20 days

* The statements and conclusions of the authors are the result of their own study and do not necessarily reflect the policy or opinion of the United States Armed Forces.

weakness of his right arm and leg, and loss of temperature sensation in both legs for the previous 2 months.

Examinations. Physical examination was negative with the exception of induration of the soft tissues at the site of the previous tumor. Neurological examination revealed a spastic-ataxic gait, weakness and hyperreflexia of the right arm and leg, bilateral absence of superficial abdominal and cremasteric reflexes, and Babinski signs. There was a sensory level to pain and temperature stimulation at the inguinal ligament on the right and at D7 on the left. He was mentally clear, speech was normal and the cranial nerves were intact. X-ray films of the chest, skull and cervical spine were normal. Pantopaque and air myelograms showed no abnormalities. The spinal fluid, on two examinations, contained 55 and 65 mg. per cent of protein but was otherwise normal. Blood and urine were normal.

FIG. 1. *Case 1.* Section of cervical spinal cord showing necrotizing myelitis. Hematoxylin-van Gieson stain, ×7.

Course. The patient's neurological disorder continued to progress. By May 20, there was weakness of all muscle groups, generalized hyperreflexia and a sensory level to pain and temperature sense below C6. Sphincter control was subsequently lost. On June 23, there developed impairment of the sense of position in all extremities, of vibratory sensation at both ankles and of touch sensation on the right side. Because of increasing difficulties in breathing, a tracheotomy was performed and on June 28 he was placed in a respirator. He expired on July 3, 1953.

Autopsy. The essential findings, outside the central nervous system, were fibrosis and vascular sclerosis but no tumor in the nasopharynx, and massive pulmonary atelectasis.

Central Nervous System. The brain weighed 1335 gm. and was neither grossly nor microscopically remarkable. The cervical region of the spinal cord was swollen and friable. Microscopically, all cervical segments showed widespread involvement. The white matter had undergone diffuse necrosis and demyelinization which affected the

lateral, posterior and anterior columns in order of decreasing severity (Fig. 1). In the most necrotic regions there was tissue disintegration, with occasional petechial hemorrhages but no reaction. Scattered intramedullary blood vessels were thickened because of deposits of a homogeneous "fibrinoid" substance which stained reddish-blue with hematoxylin-eosin stain, and yellowish-brown with hematoxylin-van Gieson preparations, but did not stain for amyloid. This substance tended to spread

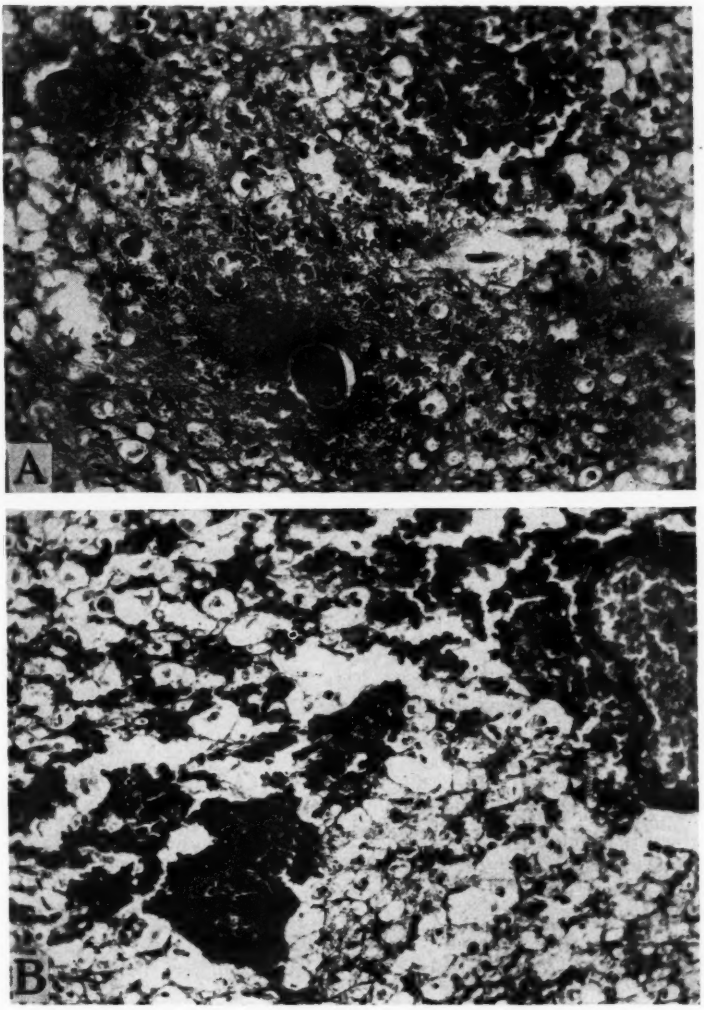

FIG. 2. *Case 1.* (A) Necrosis of myelin and "fibrinoid" degeneration of blood vessels in cervical cord. Hematoxylin-van Gieson stain, ×100. (B) Extravasation of "fibrinoid" material from the blood vessels into the surrounding white matter. Hematoxylin-eosin stain, ×200.

from the blood vessels into the surrounding tissue, accompanied by exudation of degenerating leucocytes (Fig. 2). Despite the severe breakdown of myelin, fat deposits in phagocytes were relatively sparse, glial reaction was limited to scattered gitter cells and protoplasmatic astrocytes, and inflammatory reaction was lacking. By contrast, the grey matter of the cervical cord showed no signs of disintegration, but there were degenerative changes in neurons in the form of "axonal reaction" accompanied by a more vigorous proliferation of astrocytes and glial fibers, and by perivascular and meningeal infiltrations with lymphocytes and plasma cells (Fig. 3). Above and below the cervical region, only mild primary changes could be found in the lower part of the medulla and upper levels of the dorsal cord. There was however distinct Wallerian ascending and descending tract degeneration in all parts of the spinal cord.

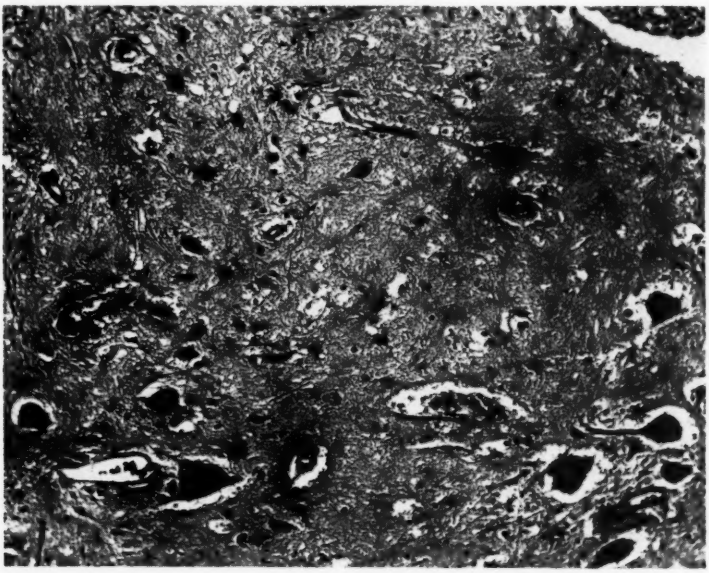

FIG. 3. *Case 1.* Anterior horns of cervical cord showing "axonal" reaction of neurons, proliferation of astrocytes and perivascular cuffing with lymphocytes. Hematoxylin-van Gieson stain, ×150.

Case 2. *History.* R.H., a white female, aged 37 years, was well until July 1946, when, following a minor head injury, headaches and right-sided Jacksonian convulsions developed. In January 1947, Dr. William T. Grant performed a left-sided frontotemporal craniotomy after ventriculography had demonstrated a shift of the ventricles to the right. At surgery, there was marked thickening of the arachnoid and cheesy material overlay the cortex. A biopsy disclosed leptomeningeal scar but no tumor tissue. The patient remained well until November 1947, when the focal convulsions began to recur. These at first responded to anticonvulsant medication, but in December 1948, they became severe enough to require hospitalization.

Examination at this time revealed aphasia, hyperactivity of all tendon reflexes, an equivocal Babinski sign on the right and slight papilloedema. The cerebrospinal

fluid showed a pressure of 230 mm. of water, a positive Pandy and a total protein of 179 mg. per cent. It was felt that there was recurrence of the lesion in the left hemisphere. However, ventriculography disclosed surprisingly a marked shift to the left.

Operation. There was a large infiltrating tumor in the right parieto-occipital region; 160 gm. of tumor were removed. Histological diagnosis was sarcoma.

Course. Postoperatively, the patient was given 20 X-ray treatments over a period of 25 days through two ports, 2650 r (air) being administered to the right and 2750 r (air) to the left temporo-parieto-occipital region (Table 2). It was calculated that the tissue dose at the midplane of the head at a depth of 7.25 cm. was 3573 r.

TABLE 2

Portal	Area	Field Size	KV	MA	HVL	F.S.	Rate	Total r (air)	Total r (skin)	Duration
#1	R. Temporo-parieto-occipital	10×10 cm.	1000	3	2.6 mm.Pb	84 cm.	20 r/min.	2650	3800	25 days
#2	L. Temporo-parieto-occipital	10×10 cm.	1000	3	2.6 mm.Pb	84 cm.	20 r/min.	2750	3800	25 days

Treatments were terminated on Jan. 21, 1949 and she was discharged from the hospital.

There were no further symptoms until October 1950, 21 months later, when severe convulsions again developed, now associated with signs of progressive mental deterioration.

Examination on readmission, December 1950, disclosed marked impairment of memory, constant involuntary movements, bilateral spastic weakness with hyperreflexia and equivocal Babinski signs, a diminution in all sensory modalities on the left side and a right homonymous visual field defect. There was, however, no evidence of increased intracranial pressure. On the assumption that there might be a recurrence of tumor, ventriculography was performed which now revealed generalized dilatation of all ventricles, more marked on the right, and only slight shift to the left. An EEG showed irritative foci in both hemispheres. The ventricular fluid contained 25 mg. per cent of protein.

Subsequent Course. The patient's condition progressively deteriorated. She became completely unaware of her surroundings, showed forced laughing, unintelligible speech, torsion movements of the head and pronounced spasticity. Towards the end there was marked difficulty in swallowing and coughing and she expired on Oct. 8, 1952, of bronchopneumonia.

*Autopsy.** *Central Nervous System.* The brain was severely atrophied bilaterally, including the cortex, basal ganglia, and white matter; the ventricles were enlarged throughout. There was no gross evidence of tumor.

Microscopically, two tumor nodules, a few millimeters in size, were found in the putamen and substantia nigra on the right side. These showed central areas of necrosis which were bounded by round cells with hyperchromatic nuclei and frequent mitoses, and pervaded by a network of reticulin, characteristic of sarcoma (Fig. 4). The most conspicuous change, however, was widespread degeneration of both cerebral hemispheres. In the cerebral cortex, the changes were patchy and varied from areas of cystic degeneration of the tissue which was held together by glial fibers

* Acknowledgement is made to Drs. M. Zeifert and J. J. Bocian of Fresno, California, for making this material available for study.

(Fig. 5) up to foci of diffuse depletion of neurons accompanied by proliferated micro- and macroglia. The cerebral white matter was more extensively involved. The myelin, with the exception of the U-fibers, was largely destroyed, accompanied by moderate amounts of fat droplets in gitter cells (Fig. 6). A dense gliosis replaced the white matter (Fig. 7A) but only scattered blood vessels showed sclerosis and hyalinization of their walls (Fig. 7B). There were rare infiltrations with lymphocytes of perivascular spaces and leptomeninges. Besides the cerebral white matter, the corpus cal-

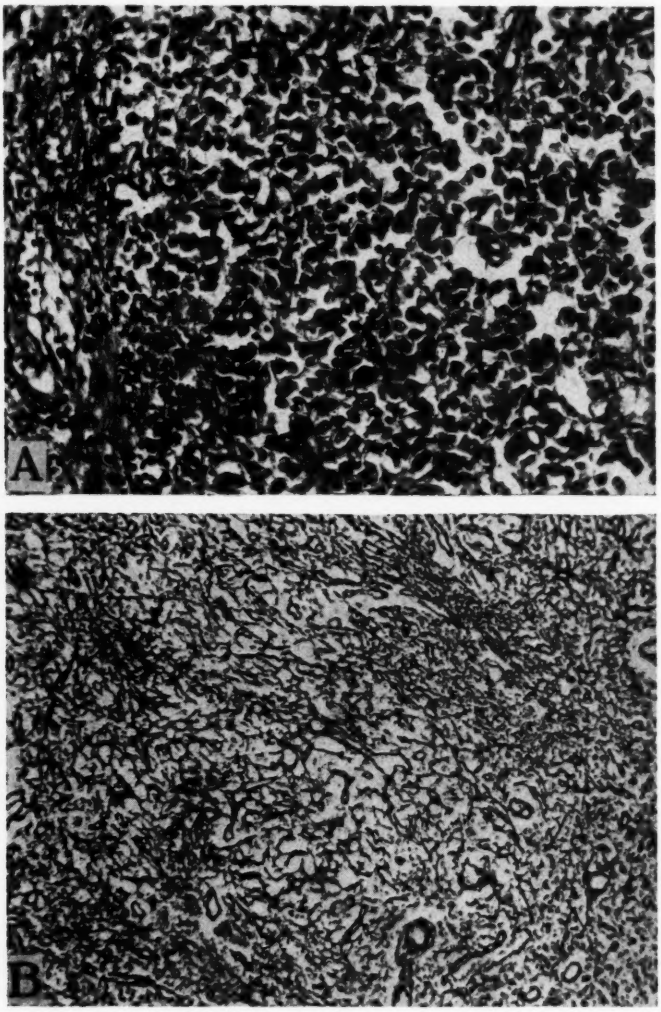

FIG. 4. *Case 2.* Tumor nodule in brain. (A) Round cells with hyperchromatic nuclei. Hematoxylin-eosin stain, ×200. (B) Diffuse reticulin. Laidlaw stain, ×50.

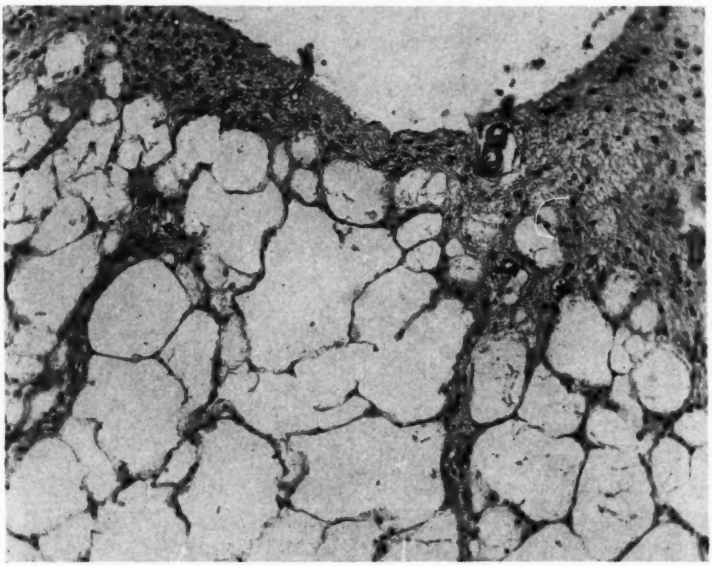

FIG. 5. *Case 2.* Cystic degeneration of cerebral cortex. Hematoxylin-van Gieson stain, ×100.

losum, both internal capsules and the right fornix were severely demyelineated. There was also bilateral severe spongy degeneration of the putamen and moderate gliosis of the caudate nucleus, globus pallidus and thalamus. The lesions extended for a short distance into the right side of the tectum and tegmentum of the midbrain but the rest of the stem showed only secondary degeneration of the pyramidal tracts. There were but mild losses of Purkinje and dentate cells in the cerebellum.

COMMENT

The 2 cases reported here illustrate the effects of X-irradiation on the central nervous system, similar to those previously described in the literature. In both, there was a latent interval following treatment, varying from 10 months in Case 1, to 21 months in Case 2, before symptoms of radionecrosis appeared. The duration of the free interval, as given in the literature, has been from 4 months to 7 years. The rapid progress in Case 1 corresponded to pathoanatomic findings of an acute necrotizing myelitis associated with fibrinoid degeneration of blood vessels and only mild glial response. The more protracted course in Case 2, on the other hand, was reflected in a chronic pathologic process of cystic degeneration and/or gliosis of grey matter, demyelinization and gliosis of white matter, and sclerosis and hyalinization of blood vessels.

In any attempt at explaining such complications, besides the factor of individual susceptibility, the question of excessive dosage deserves primary consideration. Boden calculated the tolerance dose to be 4500 r in 17 days for small fields and 3500 r in 17 days for large fields, concluding that these

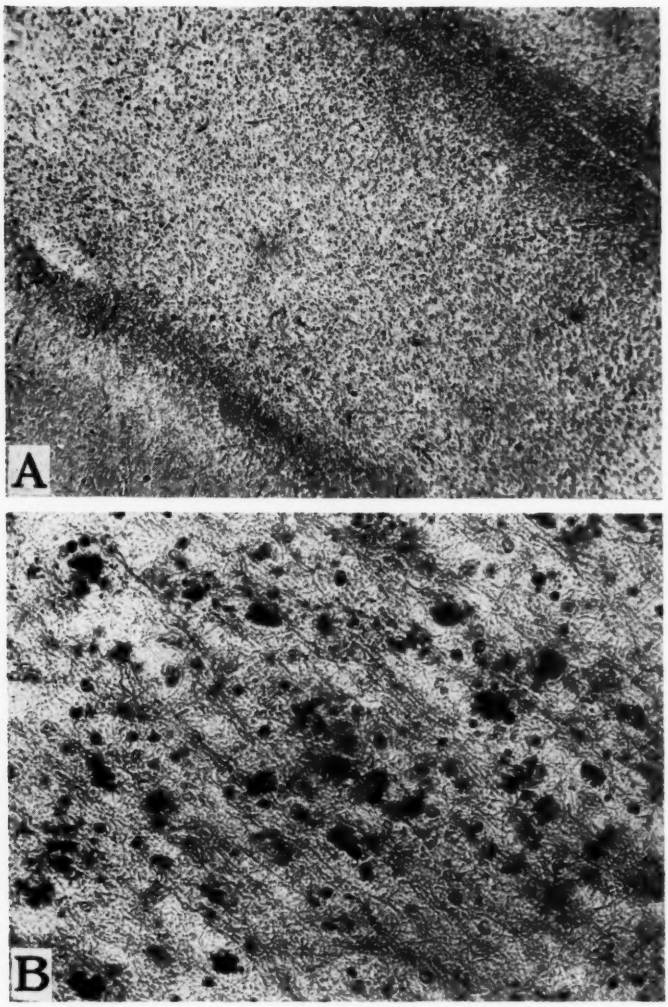

FIG. 6. *Case 2.* Cerebral white matter. (A) Diffuse demyelinization with preservation of U-fibers. Weil stain, ×32. (B) Accumulation of fat droplets. Scarlet red stain, ×100.

limits were exceeded in all reported cases of radionecrosis. There has been no general agreement, however, about such an estimate of the tolerance dose.

In experimental irradiation (Davidoff *et al.*,[4] Russell *et al.*,[9] Clemente and Holst[3]) single high doses of 2000 r and higher were found to produce similar effects but could not very well be compared with the graded dosage over a long period of time as used in radiation therapy. In a recent communication,

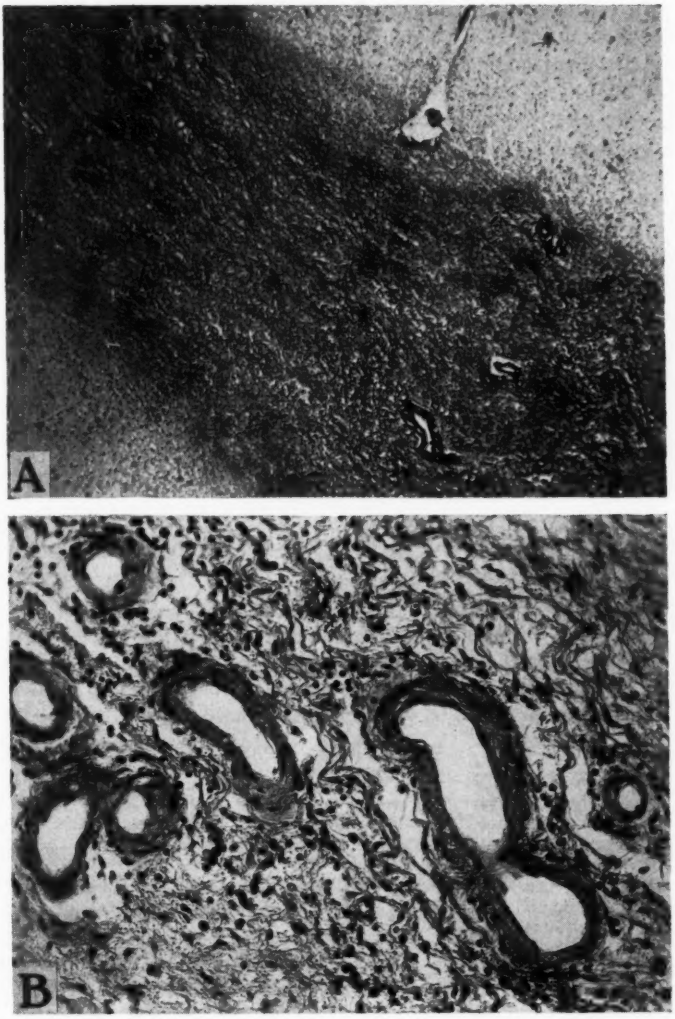

FIG. 7. *Case* 2. (A) Diffuse gliosis. Holzer stain, ×32. (B) Sclerosis and hyalinization of blood vessels in white matter. Hematoxylin-van Gieson stain, ×100.

Clemente and Holst[3] found that while single doses of 4500–6000 r applied to monkeys produced immediate brain changes, chiefly in the hypothalamus and medulla, doses of 1500 r resulted in delayed effects of cortical and subcortical myelin breakdown. It would seem that the changes observed in clinical material most closely resemble the findings in chronic animal preparations as reported by Clemente and Holst. In both conditions, the effect

is delayed, diffuse and primarily on myelin with little effect on the hypothalamus or medulla.

These observations may also bear on the question of the pathogenesis of the effect of X-irradiation. In the literature, a divergence of opinion exists as to whether we are dealing here primarily with a vascular or a parenchymal effect. In our cases both phenomena were noted, but the vascular change was distinctly limited in extent compared with the widespread disintegration of the parenchyma. In some cases reported in the literature, the reverse appears to have occurred. It might be that such differences are also related to variations in dosage. Thus, with high doses, Clemente and Holst produced intense changes in the blood-brain barrier, but apparently not with lower doses, in which case a more direct parenchymal effect was noted.

Of practical importance is the question of the incidence of radiation necrosis. Boden estimated it to be as high as 25 per cent, occurring in 11 of his 41 cases of irradiation of the brain stem or cervical cord. On the other hand, Pennybacker and Russell found only 5 in 113 cases of irradiation of the brain. The latter suspected, however, that it is more common than is generally assumed but that the exact incidence is obscured by such factors as necrosis in the tumor tissue itself, the early death from malignant tumors before delayed necrosis has had time to develop and by insufficient postmortem examination.

SUMMARY

1. Two cases of delayed radiation necrosis of the central nervous system are reported, clinically and pathoanatomically.

2. The problems of dosage, pathogenesis and incidence of such complications are discussed in the light of a review of the literature.

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PERIPHERAL COLLATERAL CIRCULATION BETWEEN CEREBRAL ARTERIES

A DEMONSTRATION BY ANGIOGRAPHY OF THE MENINGEAL ARTERIAL ANASTOMOSES*

MAJOR HAROLD ROSEGAY, M.C., U.S.A., AND KEASLEY WELCH, M.D.†
Neurosurgical Service, Letterman Army Hospital, San Francisco, California

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AN OPPORTUNITY does not often arise to observe the functioning of the peripheral anastomoses between intracerebral arteries. For one thing, the type of case required is one in which there is an occlusion of the proximal part of a major cerebral artery, and this is not often encountered in routine angiography. For another, the angiogram will not be revealing unless the exposure happens to be made at the precise instant of passage of contrast substance through the collateral vessels.

Occlusive thrombosis of the proximal segment of a cerebral artery is not common, and the diagnosis is made clinically more often than justified by either angiographic or autopsy data. As more studies, both from angiography and autopsy, have become available the impression is gained that cerebral infarction caused by thrombosis is much more often the result of carotid occlusion than of cerebral artery occlusion.[9,14] In the literature on angiography there is a striking preponderance of cases of carotid thrombosis.[10,18,21,22,32,34] Proximal thrombosis of a cerebral vessel is infrequently illustrated by angiograms.[2,20] Krayenbühl[19] has reported 2 cases of thrombosis of the middle cerebral artery and 4 of the anterior cerebral, all verified by angiography, but there were in the same series 18 cases of carotid thrombosis.

Other cases suitable for the study of the collateral circulation are those in which the patients have survived imperative and unavoidable ligation of a major cerebral artery. Postoperative angiograms may then reveal the extent of the collateral circulation in the territory of the occluded vessel.

The first case described here is one of segmental thrombosis of the proximal part of the right middle cerebral artery. It represents an ideal, though unfortunate, natural experiment for the demonstration of the functional validity of the meningeal arterial anastomoses inasmuch as retrograde filling of the proximally occluded middle cerebral artery is shown to occur from branches of the anterior cerebral. The second case also demonstrates this retrograde filling. It is one in which the right middle cerebral artery had been permanently occluded in the Sylvian fissure during isolation of an

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† Present address: Department of Surgery, University of Colorado, Denver 7, Colorado.

aneurysm, and in which complete recovery from a total hemiplegia subsequently took place. The angiograms of the third case demonstrate flow in the reverse direction, from the middle to the anterior cerebral artery. For this to occur, the proximal connections of the anterior cerebral artery with the circle of Willis must be completely interrupted. This condition was met in this case because the left anterior cerebral had been clipped in the course of isolating an aneurysm of the anterior communicating artery, and the right anterior cerebral had undergone postoperative thrombosis.

CASE REPORTS

Case 1. On Nov. 11, 1953, a 5½-year-old girl, previously well, suddenly had numbness of the left foot, followed by numbness and then paralysis of the left leg and arm. The child's mother noted drooping of the left side of the face, with drooling from the corner of the mouth. There were no convulsive movements, nor was there loss of consciousness. The paralysis cleared within an hour. Two days later this episode was repeated, lasting 30 minutes, and on November 15 there was paralysis of the left foot for 10 minutes. She was seen as an outpatient on November 17, and admitted for study.

Examination. At this time no neurological changes could be detected. The visual fields were normal. Blood count, urinalysis and x-rays of the skull were normal.

On the evening of November 18, generalized headache developed. The temperature was 100.2°F., and she appeared ill. When seen the next morning she had a flaccid left hemiplegia. Deep tendon reflexes were markedly depressed on the left. The left plantar response was extensor. The tongue protruded to the left and elevation of the left shoulder was weak. There was no impairment of consciousness, no speech difficulty or field defect. The neck was not stiff.

Angiography. A vascular malformation was suspected and right common carotid angiography was done. Ten cc. of 35 per cent diodrast were injected and three exposures were made in the lateral position, at intervals of approximately 1 sec., the cassettes being pulled by hand. This was repeated to obtain stereoscopic lateral films, and then a third injection was made for a single AP film. In the first film in the series filling of the anterior cerebral artery to the posterior limits of the pericallosal and callosomarginal branches was seen (Fig. 1). There was no evident filling of the middle cerebral artery. A fine vessel running obliquely across the territory of the middle cerebral was considered to be the superficial temporal artery. On the second film, made 1 sec. later, retrograde filling of the middle cerebral from the internal frontal branches of the callosomarginal artery was seen (Fig. 2). A diagnosis of thrombosis of the most proximal segment of the middle cerebral artery was made. Rheumatic fever and subacute bacterial endocarditis were excluded as etiologic possibilities.

Course. For treatment following the arteriography CO_2 inhalations were given to produce vasodilatation of the collateral vessels, but this did not noticeably influence the paralysis. A single stellate block was also without effect. Within the first week there was return of reflexes and tone to the left lower extremity and lessening of the left facial weakness. On a supervised program of physical rehabilitation gradual improvement was noted, so that on December 3 it was recorded that there was some return of power in the left hip flexors and commencing contraction of the left quadriceps.

FIG. 1. *Case 1.* The anterior cerebral artery and its branches are filled; the middle cerebral is not. ST = superficial temporal artery.

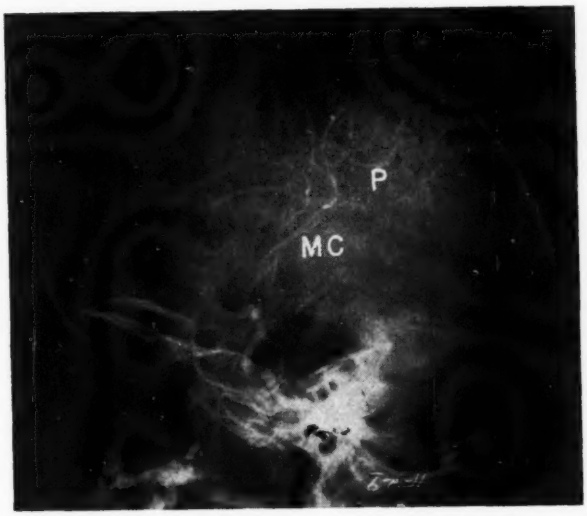

FIG. 2. *Case 1.* Exposure made 1 second after Fig. 1. Retrograde filling of the middle cerebral (MC) from the internal frontal branches of the callosomarginal is seen. P = parietal artery.

When seen for follow-up examination 2 months later she walked with a hemiplegic gait. Associated movements of the left arm were lacking. There was shortening of the Achilles tendon as a result of the extension of the foot. The hand was, for practical purposes, functionless. It was pronated and the fingers were flexed, but the biceps and triceps and shoulder girdle movements were good. Spasticity, with hyperreflexia, and an extensor plantar response were present. The left facial weakness was barely discernible. Two-point discrimination, position sense, and tests for stereognosis were normal. There was no field defect. She had been enrolled in school and was attending regularly.

Summary. A 5½-year-old child had three episodes of transient left-sided weakness within 1 week, culminating, on the fourth attack, in a flaccid hemiplegia. On right carotid angiograms segmental thrombosis of the most proximal part of the middle cerebral artery was seen (Fig. 1), with excellent retrograde filling of the distal part of the middle cerebral from branches of the anterior cerebral (Fig. 2). A very limited recovery from paralysis was subsequently made.

Case 2. A 30-year-old woman, on Oct. 3, 1953, suffered a subarachnoid hemorrhage, followed by five convulsive seizures.

Examination. Weakness of the left extremities and a left extensor plantar response were noted. There was a large subhyaloid hemorrhage in the right retina, with loss of central vision, and minute scattered hemorrhages were present in the left retina. There was focal headache behind the right eye.

Within the next week the headache diminished and focal neurological signs disappeared, except for a large central scotoma on the right. B.P. was 114/68. There was no cortical sensory loss.

A diagnosis of rupture of an intracerebral aneurysm was made.

1st Angiography. On October 16 right common carotid angiography was done and an aneurysm of the middle cerebral artery, 1.3 cm. in diameter, and located 2 cm. from the bifurcation of the carotid, was seen. On the AP film filling of the left side was also obtained by compression of the left carotid during the injection. No lesion was seen on the left. A vertebral angiogram was also normal.

Operation. On Oct. 19, 1953, right frontotemporal craniotomy was done. The dura mater was blue, and when it was incised a large quantity of xanthochromic fluid escaped. A subdural hematoma, 0.5 cm. in thickness, was present over the hemisphere. The brain pressure was too high for proximal control of the middle cerebral artery to be achieved. The aneurysm was then directly approached through the superior temporal convolution; its dome was uncovered 1 inch beneath the cortex, and it was isolated and collapsed by clipping one large entering and two leaving vessels. These vessels were thought to be branches of the middle cerebral and not the main trunk.

Prior to the direct exposure of the aneurysm 25 mg. of hexamethonium chloride were given. During the application of clips to the vessels the blood pressure was 60–70/40. During the closure of the wound it rose to 70–90/50.

Course. Immediately postoperatively, when the depth of anesthesia had lightened and while the blood pressure was still in this range, examination of the patient was done. The right extremities withdrew from painful stimuli; the left did not. The skin was cold, her color ashen. As transfusion was continued her color improved, and 2 hours after the previous examination the blood pressure rose to 100/60, and a with-

drawal response to pin prick was elicited from the left foot and leg. There was no response from the upper extremity. The next day she could move and lift the leg, and feeble movements of the shoulder were present. On the 2nd postoperative day weak flexion of the elbow returned.

On October 23 (4 days postoperative) the following notes were made: "There is good spontaneous recovery of the left leg, but the arm has lagged. There is adequate functional power in all hip groups, left quadriceps and hamstrings. The foot shows only a trace of movement. Scapular fixation is fair, and there are some gross shoulder movements through a limited range. There is no function below the elbow."

On November 4 (15 days postoperative): "In the leg there is full use of all groups except for dorsiflexion of the foot. Eversion is poor. There is weakness of the glutei, lateral hamstrings, and the soleus group. Internal rotation of the hip is poor. In the arm there is recovery of the scapular fixators and the deltoid. The elbow groups are good, including the triceps. Pronators are stronger than supinators. There is remarkably good power in the fingers, though the thumb groups are still weak."

By November 17 she was walking; the gait was spastic. The left facial weakness was still present, the tendon reflexes were hyperactive on the left, and a left extensor plantar response was present. Movements of the left arm and hand were good, though paretic.

On Nov. 19, 1953, the day of discharge, an evaluation of muscle function was as follows: "She walks well and bends the knee and ankle in the swinging phase. Hand function is good, and is better than shoulder function. Deltoid, biceps, and triceps are good. Thumb extension, flexion, abduction and opposition are only fair."

On Feb. 4, 1954, the patient was seen for follow-up examination. She stated her activity had recently been unlimited and included golf. The neurological improvement was remarkable. The gait was normal, without spasticity or circumduction. The left foot dorsiflexed well. The arm swung in walking. Gross muscle testing revealed good strength everywhere. Precise movements of the fingers, and alternating movements of the hand, were done accurately. Reflexes were hyperactive in the left arm and leg. There was no increased tone on passive manipulation of the arm or leg. The plantar response was indefinite. Facial weakness was barely discernible. Two-point discrimination was normal. No field defect could be detected on confrontation.

2nd Angiography. Right common carotid angiography was repeated. On the first film in the series normal filling of the anterior cerebral, the posterior communicating, and the posterior cerebral arteries was seen (Fig. 3). The presence of an additional pedunculated aneurysm at the point of origin of the posterior communicating artery was noted. Hemostatic clips were seen on the previous aneurysmal sac and on the middle cerebral artery. On the AP film the proximal one inch of the middle cerebral was seen to fill faintly but definitely. Distal to the clips the occlusion of the vessel was apparent. On the second film, approximately 1 sec. later, there was reflux filling from branches (L^1, L^2, L^3) of the anterior and posterior cerebrals into the middle cerebral (Fig. 4). The latter vessel was faintly outlined, but it was exactly similar, branch for branch, to its preoperative configuration.

Summary. A 30-year-old woman, following a subarachnoid hemorrhage, was shown by angiography to have an aneurysm of the right middle cerebral artery in the Sylvian fissure. At operation, with hexamethonium as an adjunct, the aneurysm was isolated and collapsed by hemostatic clips. Immediately postoperatively, while hypotension still persisted, the right extremities withdrew from painful stimuli, the left did not. With return of the blood

pressure to its normal level, response to painful stimuli could then be elicited from the left foot and leg. Recovery of function from this point on was rapid. Four weeks later there was only minor residual weakness in the hand. Examination 3½ months postoperatively disclosed only left-sided hyperreflexia, with normal function in the arm and leg. Right carotid angiography was repeated and it was seen that the middle cerebral had been completely occluded at operation (Fig. 3). In addition, retrograde filling of the distal por-

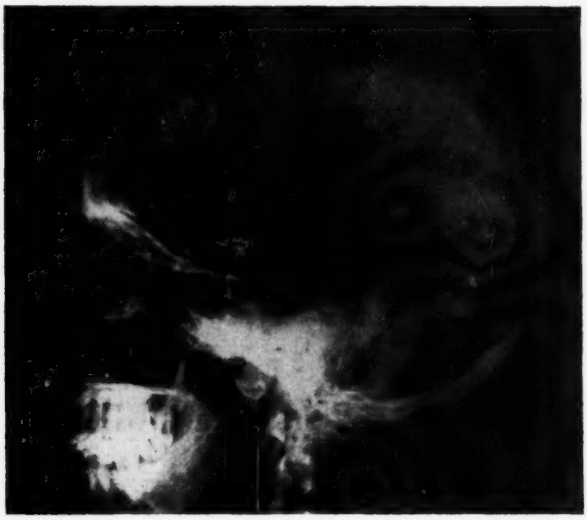

FIG. 3. *Case 2.* The anterior and posterior cerebrals are seen. The hemostatic clips are on the collapsed and isolated aneurysm of the middle cerebral; this vessel is occluded, and does not fill.

tion of the middle cerebral from branches of the anterior and posterior cerebrals was noted (Fig. 4).

Case 3. A 33-year-old woman with a 6-year history of essential hypertension (B.P. 170/110) had a sudden headache on March 29, 1953, collapsed, and was admitted to a hospital. No localizing neurological signs were noted but there was confusion, restlessness, and nuchal rigidity. The spinal fluid initially was bloody. On April 1 it was xanthochromic, but on April 7 it was again bloody, and she was transferred to Letterman Army Hospital on April 9.

Examination. B.P. was 160/94. She was cachectic, mentally obtunded, and cooperated in the examination only with great difficulty. There was a large subhyaloid hemorrhage in the left retina. All extremities were weak, the right lower being the worst. Deep tendon reflexes were equally depressed everywhere. There was a right extensor plantar response, and abdominal reflexes were absent on the right. There was no cranial bruit. The pupils were equal and reacted normally, no ocular palsy was noted, and corneal sensitivity was normal.

1st Angiography. An aneurysm was suspected, and so on April 14 left internal carotid angiography was done. On the films a 7 mm. aneurysm of the left anterior

cerebral, at its junction with the anterior communicating, was seen. The aneurysm did not fill when the right carotid was injected.

Course. On ventriculography, done on April 20, dilatation of the entire ventricular system, without evidence of a focal intracerebral hemorrhage was seen. On April 23 she had a generalized seizure followed by coma, and lumbar puncture yielded markedly bloody fluid.

Operation. A left frontal craniotomy was done, and the left anterior cerebral artery was clipped proximal and distal to the aneurysm.

Course. The following morning she was awake, spoke a few words, and moved all extremities, but in the next several days her condition deteriorated into the akine-

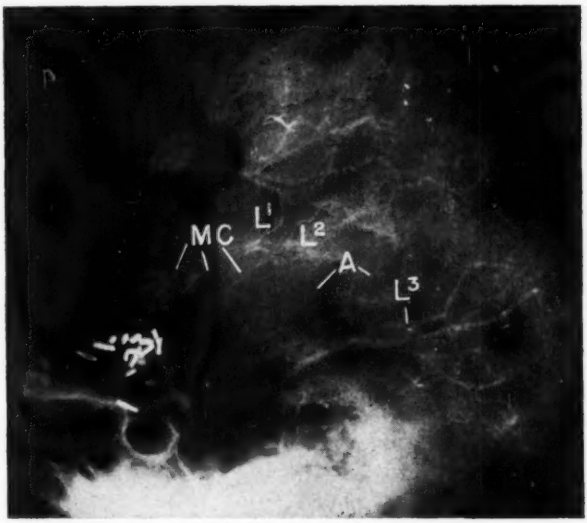

FIG. 4. *Case 2.* Exposure made 1 second after Fig. 3. Retrograde filling of the candelabra (MC) of the middle cerebral through anastomotic loops (L^1, L^2, L^3) of the anterior and posterior cerebrals is seen. A = angular artery.

tic state so aptly called coma vigil. The ventriculogram was repeated on May 4, and progressive dilatation of the ventricles was noted.

2nd Angiography. Right internal carotid angiography was done on May 11. On the first film (Fig. 5), a small amount of diodrast was visible in the most proximal portion of the right anterior cerebral artery (AC); the remainder of the vessel did not fill. The candelabra of the middle cerebral artery was outstanding. On the third film in the series, made 2 or 3 sec. later, diodrast was seen in the internal cerebral veins and straight sinus (Fig. 6). The striking finding was the late filling of the callosomarginal artery (CM) and its frontal branches. This was interpreted as reflux filling from the middle cerebral.

Course. Her inertia was profound. She made feeble movements of the arms and legs in response to pin prick, but there was no spontaneous effort. The eyes were wide, fixed and staring. She regressed gradually, the terminal course being complicated by an ependymitis, which occurred following ventricular puncture, and she expired on Aug. 27, 1953.

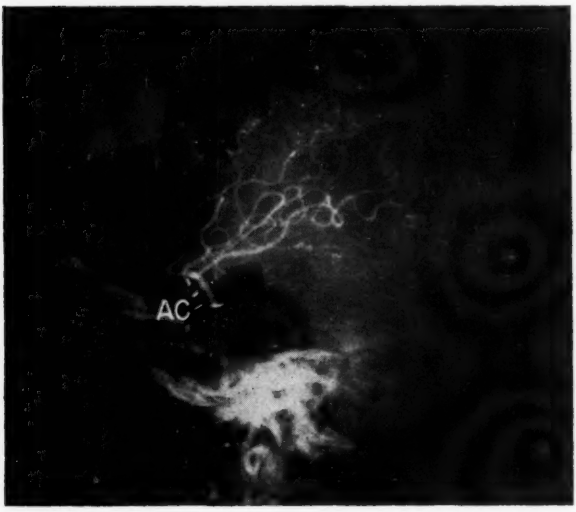

FIG. 5. *Case 3.* The anterior cerebral underwent postoperative thrombosis and only its most proximal portion (AC) is seen. The candelabra of the middle cerebral is outstanding.

Autopsy. The pertinent findings in the examination of the brain were: (1) the aneurysm of the left anterior cerebral artery and thrombosis of both anterior cerebrals; (2) softening of the inferior cingulate region, the recto-orbital area, the rostrum of the corpus callosum, and the inferior portion of the corpus striatum on the left; softening of the inferior cingulate region on the right; (3) atherosclerosis and arteriolar sclerosis of the cerebral vessels.

Summary. A 33-year-old woman, with essential hypertension, suffered three subarachnoid hemorrhages from an aneurysm of the anterior communicating artery. Since the aneurysm was shown on angiography to fill from the left carotid but not from the right, the left anterior cerebral was clipped proximal and distal to the aneurysm. On postoperative right carotid angiograms occlusion of the right anterior cerebral was seen (Fig. 5), and this was presumed to be caused by thrombosis. Both anterior cerebrals were therefore occluded. The right anterior cerebral artery, distal to the occlusion, filled from branches of the middle cerebral (Fig. 6). The course was one of progressive deterioration over a 4-month period. Postmortem examination of the brain disclosed extensive softening in the territory of the left anterior cerebral, and moderate cerebral atherosclerosis.

DISCUSSION

Many anatomical studies on the subject of peripheral anastomoses between cerebral vessels are to be found in the literature,[4,5,12,13,28,29] and on the basis of these studies it has long been known, in a general way, that the cerebral arteries are peripherally confluent. Microscopic preparations of these

areas of confluence have shown the existence of widespread capillary and arterial anastomoses in the cerebral cortex and pia-arachnoid.[1,6,8,24,25] Nevertheless, impetus and direction were given this subject through the publication by Vander Eecken and Adams[33] of their paper on "The anatomy and functional significance of the meningeal arterial anastomoses of the human brain." In this publication specific dissectable meningeal anastomotic channels were described, correlations were made with clinical and pathologic findings in cerebrovascular thrombosis, and the physiologic mechanisms by which the cerebral cortex is protected against ischemia were discussed. Paramount among their conclusions was the importance of the role played in collateral circulation by the meningeal arterial anastomoses. Our clinical observations support this to the fullest degree.

The principal anastomotic channels they listed[33] are as follows: Between the internal frontal branches of the callosomarginal, the paracentral branch, and the precuneal branch (all from anterior cerebral) and, respectively, the precentral, central, and parietal branches (all from middle cerebral); between the angular branch of the middle cerebral and the parieto-occipital branch of the posterior cerebral; and between the precuneal or posterior callosal branches of the anterior cerebral and the parieto-occipital branch of the posterior cerebral. Regarding the number and the total size of these anastomotic channels the same authors found that the anterior cerebral-middle cerebral anastomosis had the greatest total width, with the middle cerebral-posterior cerebral following closely, and the anterior cerebral-posterior cerebral by far the lowest. It was also found that the over-all meningeal

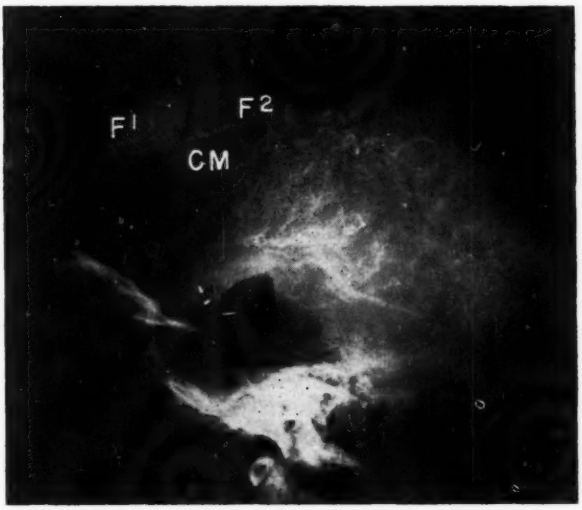

FIG. 6. *Case 3.* Exposure made 2–3 seconds after Fig. 5. Filling is in the venous phase but late retrograde filling of the callosomarginal (CM) and its internal frontal branches (F^1, F^2) is seen.

anastomotic bed in some specimens was as much as twice that in others. As they point out, this latter variability, and the extent to which arteriosclerosis may compromise the total anastomotic bed, will together constitute a major influence in determining the outcome following an occlusive accident. Since each major vessel has a constant territorial distribution, it is clear that the variability in the consequences of occlusion of any one vessel will depend largely on the efficiency of the collateral circulation. "In cases in which anastomotic vessels are large and numerous, occlusion of a large brain artery causes less extensive infarction than if these vessels were small and poorly developed."[33]

Angiographic evidence of this peripheral collateral circulation was already available when the above conclusions were reached, but went largely unnoticed. In a long dissertation on the normal and abnormal angiography of the anterior cerebral artery Ethelberg[11] discussed and illustrated the collateral circulation in 2 cases of occlusion of the middle cerebral artery. His figures show the overflow from the anterior cerebral into the territory of the middle cerebral. This was recognized as reflux filling, and the significance of this in attenuating the symptoms of proximal cerebrovascular occlusion was clearly stated: "Depending on the degree to which collateral circulation has been developed, symptoms may never occur . . . or they may display the whole gamut from the faintest to the fully developed syndrome of the middle cerebral artery."[11]

Examination of the angiograms in Case 1 should leave no doubt that collateral circulation indeed occurs. It will be noted that the reflux filling of the middle cerebral stops short of the carotid siphon, leaving a filling defect which may represent the occluding thrombus (Fig. 2). The presence of this defect makes it impossible to interpret the late appearance of the middle cerebral artery simply as delayed filling from the carotid. The conclusion is inescapable that the middle cerebral filled from the anterior cerebral through anastomotic vessels. In Fig. 3 (Case 2) the operative occlusion of the middle cerebral artery is seen. The most proximal clip is 1 inch from the bifurcation of the internal carotid. In Fig. 4, 1 second later, the reflux filling of the middle cerebral (MC) through anastomotic loops (L^1, L^2, L^3) from the anterior and posterior cerebrals is demonstrated. In Fig. 6 (Case 3), where both anterior cerebrals have been occluded, retrograde filling from the middle cerebral into the callosomarginal artery and its branches is seen. Taken altogether these findings are strong evidence that the meningeal arterial anastomoses function to join all three cerebral arteries. Indeed, Petersen and Evans[23] had remarked long ago that ". . . clipping of the middle cerebral artery near its origin does not result in a cessation of flow in the tributaries of the artery," and Hain *et al.*,[16] have observed experimentally the refilling of the distal part of the middle cerebral after proximal clipping.

The angiograms are also in fine agreement with the anatomical description of the principal anastomotic channels. For example, in Fig. 2 the angular artery, the most posterior branch of the middle cerebral, is not filled.

At first glance the impression is gained that the middle cerebral group as a whole is elevated. Actually, however, this is not so, for the most posterior branch seen conforms in position not with the angular but with the postparietal artery (P). The angular artery is absent. The explanation for this would be obscure were it not known from anatomical studies[33] that the postparietal artery is the most posterior branch of the middle cerebral that can be filled from the anterior cerebral, and that the angular artery fills only from branches of the posterior cerebral artery. This latter point is further illustrated in Fig. 4, where branches (L^3) from the posterior cerebral into the angular artery (A) can be traced.

A very good anatomico-pathological correlation comes out of concurrent analysis of Cases 1 and 2. In Case 1 the middle cerebral was occluded by a segmental thrombus immediately distal to its origin from the internal carotid. This is precisely the area of origin of the anterolateral striate arteries, which must also, therefore, have been occluded. These vessels, which normally contribute to the blood supply of the internal capsule and basal ganglia, belong to the paramedian group of perforating arteries and partake in no anastomoses outside the domain of their distribution. In Case 2 the most proximal clip occluding the middle cerebral was placed almost 1 inch from the bifurcation of the carotid. In the postoperative anteroposterior angiogram there was filling of the proximal segment of the middle cerebral and one may assume that the striate branches were patent. The clinical difference between the patients is remarkable. The first had a spastic hemiplegia; the second made a complete functional recovery, even to the presence of finger dexterity. If one considers that in the angiograms of each case there were functioning meningeal arterial anastomoses, it will be apparent that the difference is caused by occlusion of the perforating arteries with infarction of the internal capsule in the first case and not in the second. In connection with this, Case 1 of Vander Eecken and Adams[33] may be cited. Here there was an occlusion of the middle cerebral just beyond the origin of the anterior choroidal artery, yet at postmortem examination only a small cortical infarction surrounding the Sylvian fissure was seen, the striking finding being a cyst which replaced the putamen, outer segment of the globus pallidus, internal capsule and body of the caudate nucleus. From all these facts one may arrive at the general conclusion that, in some cases at least, the anterior and posterior cerebral arteries are capable of taking over the cortical vascular territory of the middle cerebral and that the paralysis that follows occlusion of the middle cerebral at its origin is then capsular and not cortical in origin. One can only repeat that "The most devastating effects of vascular occlusion are nearly always in the basal ganglia and brain stem. It is, indeed, unfortunate that these parts are supplied solely by non-anastomosing, penetrating arteries. . . ."[33]

On the other hand, the mere demonstration by angiography of functioning meningeal arterial anastomoses is no assurance that the pressure within the anastomotic vessels is high enough to prevent ischemia. From a study of

Case 3 it is obvious that collateral circulation may coexist with extensive softening. This is not surprising, and it has been previously suspected.[11,33] One of the most important factors determining the peripheral resistance within the anastomotic vessels is the extent to which they are affected by arteriosclerosis. In Case 3 there was a 6-year history of essential hypertension and at necropsy moderate atherosclerosis and arteriolar sclerosis of cerebral vessels were found. A situation thus existed in which the anastomotic vessels, though patent to the passage of diodrast, resisted the passage of blood sufficiently to render no practical collateral service. It is only safe to say that any optimism regarding the functional capacity of the collateral circulation is not justified when arteriosclerosis is known to exist.

A question has also been raised as to the role played by systemic blood pressure at the critical moment of vascular occlusion, when the collateral circulation must function if tissue is to survive. In 1939 Poppen[26] observed that ligation of the anterior cerebral arteries could be accomplished without untoward changes in the state of consciousness provided the blood pressure was maintained, but when hypotension supervened ligation was then followed by permanent unconsciousness. Schorstein[27] noted that catastrophes resulting from carotid ligation were most numerous when there was coexistent systemic hypotension, and remarked that "The results of carotid ligation are dependent . . . on the systemic blood pressure which is so important in maintaining the efficiency of the cerebral circulation." In experimental occlusion of both anterior cerebrals in monkeys, with and without systemic hypotension, Thompson and Rhode[30] stated that ". . . with increasing grades of hypotension, collateral circulation to the ischemic neurons is progressively decreased with resultant neurologic sequelae. Conversely, . . . maintenance of normal blood pressure permits maximum benefit to be derived from collateral circulation, with minimal neurologic sequelae." A similar investigation was carried out by Thompson and Smith[31] with regard to occlusion of the middle cerebral artery. They remarked that "In both dogs and monkeys with normal blood pressure the exposed cortex surface showed no visible change following occlusion. With arterial hypotension, however, the surface vessels showed sluggish refilling as compared to the pre-occlusion filling. . . . In the hypotensive monkeys a complete permanent hemiplegia resulted. . . . The monkey ligated with normal systemic pressure quickly regained his strength and within twenty-four hours was, for practical purposes, functioning normally." At subsequent postmortem examination the animals undergoing hypotensive occlusion showed gross cortical atrophy and reduction in ganglion cells, whereas the normotensive animals showed only minimal histologic variation. With regard to this an interesting and pertinent clinical observation may be cited. In discussion of the above paper Aring[3] stated that "Physicians are becoming aware of the cerebral debut of coronary occlusion, the ineffectual cardiac muscle delivering an unsatisfactory supply of blood to areas of the brain whose vessels perhaps had been previously compromised. . . . The stroke may . . . represent the most obtrusive sign of coronary occlusion."

In Case 2 interesting observations were made in this connection. During the isolation of the aneurysm the blood pressure was kept in the range of 60–70/40 by the administration of hexamethonium. During the final stages of closure the range was 70–90/50. Two hours after the right middle cerebral artery had been permanently occluded, and while the blood pressure was at the latter level, the patient had recovered sufficiently from the anesthetic to allow of examination. There was a good withdrawal response to pin prick in the right face, arm, and leg, but none on the left. Within the next 2 hours the skin color changed from ashen to pink, the blood pressure stabilized at 100–110/60, and withdrawal of the left foot and leg in response to pin prick appeared. From this point on there was progressive improvement, which is described in detail in the case report.

For the ultimate recovery in this case, in which the occlusion of the vessel was acute and complete, one must give full recognition to the circulatory capacity of the system of meningeal arterial anastomoses, but this capacity might not have been realized had the blood pressure remained longer below the critical level. It would be difficult to overestimate the importance of the systemic blood pressure in a situation such as this. It is clear that the pressure within the feeding vessels is the only force available to overcome the peripheral resistance within the anastomotic bed. Assuming that the peripheral resistance remains constant, a drop in systemic blood pressure would naturally embarrass the collateral circulation. Actually, some adjustment would occur at a lower level of pressure, for the peripheral resistance would then diminish in response to local anoxia and vasodilatation. However, the balance between systemic blood pressure and peripheral resistance should, ideally, always be kept above the level at which anoxia comes into play. Where this balance is and how high the blood pressure must be maintained to serve the collateral circulation cannot be said, but on the basis of these theoretical considerations it may be concluded that deliberate systemic hypotension (which cannot be quickly reversed) is to be avoided during operations for intracranial aneurysms, in which the possibility of having to ligate a major artery always exists. The corollary of this was given by Fulton[15] in the discussion of the paper by Thompson and Smith,[31] when he stated that "No major cerebral vessel should be occluded when the blood pressure is low, if this can possibly be avoided." In the surgical approach to lesions of the major vessels proximal control of the vessel itself, for example by a loop ligature, as described by Campbell and Burklund,[7] is the ideal method of achieving control and minimizing blood loss. In this way the regulatory mechanisms that will be required to come into play instantaneously following an imperative ligation will have the greatest freedom to do so.

We do not wish to introduce any optimism into the surgical management of aneurysms of the middle cerebral artery, but only to point out that the catastrophe of permanent paralysis following occlusion of the vessel is not necessarily inevitable.[17] The reason for suggesting this is not only the good fortune of having witnessed a complete recovery in such an instance but also the knowledge that some insight into the mechanism of the peripheral

collateral circulation has now been gained. The facts appear to be these: That if the middle cerebral artery is occluded distal to the origin of the anterolateral striate branches in a young person when arteriosclerosis is not a factor and when there has been no concomitant period of severe hypotension, then under these circumstances the conditions are optimal for recovery of function. The basis for this recovery would be the assumption by the anterior and posterior cerebral arteries of the vascular supply of the occluded area by means of the meningeal arterial anastomoses.

SUMMARY

Following occlusion of a major cerebral artery, collateral circulation occurs by means of the meningeal arterial anastomoses to the extent that retrograde filling of the occluded vessel can be seen on angiograms. Three cases illustrating this are described. In the first, there was a segmental thrombotic occlusion of the most proximal part of the middle cerebral, and a very adequate collateral circulation from the anterior cerebral is shown. In the second case the middle cerebral was occluded by a hemostatic clip at a point 1 inch from its origin, and reflux filling of the distal part of the vessel by collaterals from the anterior and posterior cerebrals is shown. In the third case, in which both anterior cerebrals were occluded, retrograde filling of the callosomarginal artery is shown to occur through the anastomotic branches of the middle cerebral artery. Providing optimal conditions exist, this collateral circulation is effective in taking over the vascular supply of the cortical territory of an occluded vessel. The second case, in which there was an acute complete occlusion of the middle cerebral with immediate hemiplegia followed by rapid total recovery of function, is presented in support of this.

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A MODIFIED TECHNIQUE FOR SPINOTHALAMIC CORDOTOMY

WALLACE B. HAMBY, M.D.

The University of Buffalo School of Medicine, and the Buffalo General Hospital, Buffalo, New York

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SURGICAL section of the spinothalamic tracts of the spinal cord, conceived by Spiller[4] and developed by Frazier,[1] has been useful in the control of lower-body pain. Many carefully conducted studies have been reported relative to the precise position in the anterolateral cord quadrant of pain and temperature fibers from specific body areas. These studies have shown a degree of spatial predilection for area representation, but in clinical cases of severe pain, the most satisfactory results have followed as near as possible complete transection of the anterolateral quadrant of the cord.

The technique of cordotomy has evolved since its origin,[3] chiefly in perfection of a rather fixed surgical pattern. In general, this has consisted of resecting 2 or 3 spinal laminae, opening the dura mater and arachnoid in the midline, and severing at least 2, and often 3, pairs of attachments of the dentate ligament from the dura mater. By traction upon a dentation of the ligament, the cord is rolled as completely upon its side as possible. The degree of rotation is limited by the resistance of the nearby anterior and posterior nerve roots. A knife or a hook of some type then is introduced into the cord and a cut is made through the anterolateral quadrant as nearby as possible to a predetermined depth and extent. Several surgeons have emphasized that after the section, the patient should be awakened, if he is anesthetized, and the level of analgesia be tested to insure its adequacy.

The application of this technique has been followed by results and complications so variable from surgeon to surgeon, and from patient to patient, that the value of the procedure is by no means commonly accepted. Particularly dubious are physicians in other fields, who must care for the patients after operation.

Several years ago the writer began to doubt the validity of several of the standard assumptions basic for the existing operation. Progressive modifications in technique have gradually resulted in an operation considerably different from the usual one. Conversation with colleagues stimulated the report of this modified technique of cordotomy.

PHYSIOLOGIC BASIS FOR MODIFICATION

Anesthesia. In general, it appears to me desirable to operate upon anesthetized patients. Modern anesthetic agents and techniques make this safe.

Certainly in the case of patients whose need for surgery stems from long-continued pain, it is more merciful than is operation with local analgesia alone. The combination of mild pre-induction medication, anesthesia with intravenous pentothal sodium, with or without nitrous oxide and oxygen, and generous procaine infiltration of the surgical area has proved entirely satisfactory.

In more cases than not, I have been dissatisfied with the results obtained by testing patients immediately after tract section to determine the level of analgesia. The patient operated upon with local analgesia is often too exhausted and apprehensive, by the time that stage of the operation is reached, to give reliable responses. If he is awakened for this purpose from light anesthesia maintained through the earlier phases of the operation, his responses again may mislead the surgeon in the result to be anticipated. It seems preferable to depend instead upon a more nearly complete section of the anterolateral tracts.

Level of Section. For patients having pain in various parts of the body, individualization of the level of cord section requires variability of depth of section according to the diameter of the cord at the level of the attack. Practically all pain for which cordotomy is indicated requires the level of analgesia at or only slightly below the umbilicus. To the patient, it makes little practical difference whether his level of analgesia is at the umbilicus or at the clavicles. To make the operation as uniform as possible in performance, we have fixed upon the cervical level. In the average case, sections at C4–5 on one side and C5–6 on the other, have proved entirely satisfactory. This insures quite uniform, adequate levels of analgesia between the clavicles and the nipple level. In cases in which arm analgesia also is desired, cordotomy has proved safe at even C1 and C2 levels.

By adopting the C4–6 levels for section, it is possible to anticipate quite uniform results with a 6 mm. depth of incision in patients of average build. The incision is made 5 mm. deep in smaller patients.

Position. The sitting position has decided advantages in cervical spinal cord surgery. Bleeding is minimized, so the operating time and trauma are considerably lessened. The surgical field is more easily available to the surgeon and his assistants than in operations upon prone patients.

The patient is securely fastened in a chair with the trunk erect and the head supported in a moderately flexed position. This permits loss of cerebrospinal fluid without entirely draining the ventricular system. Acute flexion of the neck is avoided, thereby minimizing possible cord trauma against unrecognized midline disc protrusion.

Fear of surgical shock has kept several surgeons from using this position. Although it is a hazard in the case of conscious patients, anesthesia largely minimizes it. The blood pressure regularly falls a moderate amount initially, but quite regularly it regains its original level by the time draping is completed. The blood pressure usually falls temporarily to 80 mm. or even lower after the second cord section is made. In sluggish cases the administration of

vasopressor drugs is very effective. In refractory cases, blood pressure can be restored by elevation of the legs, or by placing an abdominal binder around the patient. An inflatable balloon between the binder and the patient's abdomen permits pressure to be controlled by the anesthetist. We have found that, when a competent anesthetist is in attendance, blood pressure has been entirely controllable in this position.

In the performance of cervical cord surgery in the sitting position, both surgeon and anesthetist must be aware of the possibility of air embolism. The mechanism, recognition and correction of this possible complication has been reported.[2] Should the complication occur, it must be possible to flatten the chair immediately and turn the patient on his left side. No elaborate apparatus is needed; a hinged-back chair is the only essential. In the emergency, the operative wound is covered with two sterile towels held by the surgeon while the assistants release the restraining ties and turn the patient. Thereafter, the operation may be completed after redraping, or may be deferred until another time. Now that effective protection against a fatality is possible, this rare complication need not be a contraindication to the sitting position.

Rotation of the Spinal Cord. To make an incision of precise size and extent into the anterolateral aspect of the cord from the dorsal position, the cord must be rolled toward the opposite side. The cord is "guyed" in place by the two dentate ligaments placed roughly at the centers of the sides of the cord, and by the anterior and posterior nerve roots on each side. The ligaments are short and relatively inelastic; the nerve roots are less rigid restraints to rotation, dependent upon their lengths at various levels along the cord. In the standard cordotomy, mobility of the cord is increased by severing two or three dentations of the ligament on each side.

Were the spinal cord a more rigid cylinder, sufficient traction upon a dentate ligament to displace it 45° (A, Fig. 1) would result in 45° of rotation of the cord along its axis. The approach to 45° of rotation would be limited only by the limits of length and elasticity of the nerve roots. Physically, however, the cord is not even a semirigid cylinder, but is quite soft and approaches a semiliquid, contained within a flexible sheath. The result of 45° of traction upon a surface point of such a structure does not result in a true, but rather in a distorted rotation (B, Fig. 1). The vertical diameter (a–b) curves with its convexity to the right. Tension then is exerted upon the surface by guys 2 and 3 while guys 1 and 4 are relaxed. The play of these forces distorts the cylindrical cross-section, flattening it between "y" and 3 ventrally and expanding it between "y" and 3 dorsally.

To complicate the matter still further, the restraint of the guys is not applied uniformly along the cord, but variably at the points of attachments of the nerve roots. For technical convenience, the point chosen for traction on the dentate ligament usually is about midway between the points of attachment of two posterior nerve roots. This results in an irregular distortion upward of the surface of the cord at the point of incision.

The variability of the described forces acting upon the displaced soft spinal cord results in great variation in the depth of incision into the anterolateral surface of the cord, even when using a standard depth of section. These factors seem adequate to explain the variable results obtained in even apparently similarly treated cases. It seems possible that some of the variable morbidity following standard cordotomy may result from the application to

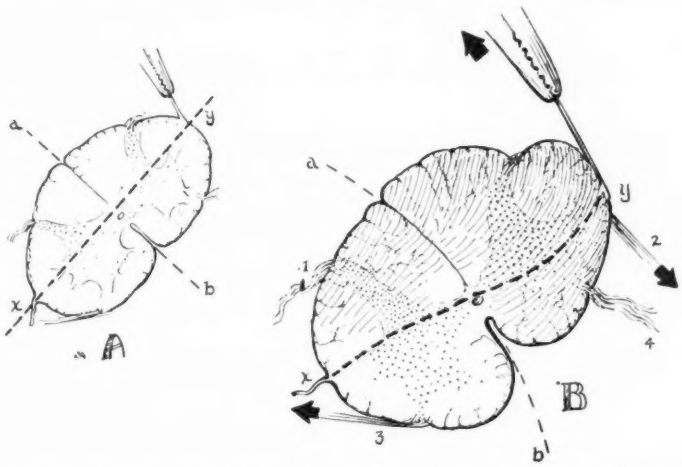

FIG. 1. Mechanics of rotation of the spinal cord. (A) Theoretical representation of the effects of 45° rotation upon a cross-section of a rigid, cord-like cylinder. (B) Theoretical representation of the effect (exaggerated) of 45° rotation of a semisolid cylinder.

the cord of the described physical forces as well as from the effects of the incision. Data from our cordotomy series are too variable to allow conclusions to be drawn concerning this possibility.

A technique was sought that would permit sections of the anterolateral surface of the cord with minimal or no amount of rotation. To attain this end, a knife* was developed that could be introduced 6 mm. into the cord through the approximately 5 mm.-wide space between the dura mater and cord. The knife (Fig. 2) consists of a fragment of a thin double-edged razor blade, held in a gripping shaft. Although the end of a spear-tipped surgical knife can be broken to the proper length and held in a fine-tipped hemostat for this purpose, such a tool is not entirely adequate. The blade is too thick and not sharp enough, and only rarely can a hemostat be found that is fine enough at its tip and yet strong enough to grip the hard and minute surface of the blade securely.

The blades for this special knife are prepared by grasping the edge of a razor blade obliquely with a smooth-jawed pliers and breaking the fragment

* This knife is obtainable from Codman & Shurtleff, Inc., Boston, Mass.

away from the blade. A desirable fragment is approximately the shape of a right triangle, 8 mm. along its base and 2 mm. on its side. To permit the grasping instrument to hold securely upon the slick, hard, 2 mm.-square surface, each blade must be coated with a thin layer of solder applied with heat insufficient to draw the temper of the steel. These tips are prepared in quantity and are cold-sterilized as needed. Such a blade can be advanced through cord substance against the resistance of simple fixation of a dentate ligament. Blades are discarded after use.

Approach to the Cord. The type of cord incision described was applied earlier through a standard laminectomy. It soon was realized that if the cord need not be mobilized, an extensive bony removal is not necessary. Even-

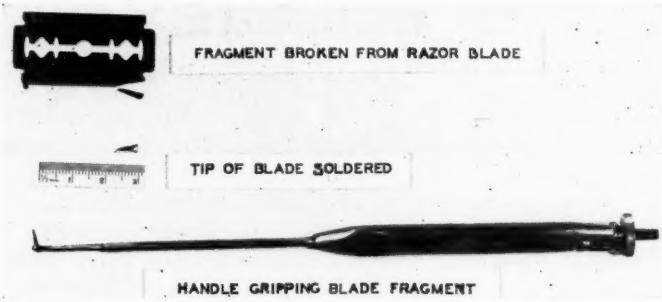

FIG. 2. Photograph of a knife handle devised to hold tips made from thin razor-blades.

tually the cord section was made through an interlaminal approach similar to that of an intervertebral disc exploration, removing portions of adjacent hemilaminae to produce a small dural exposure placed as far laterally as possible.

The dura mater is incised vertically. Closure of the dural incision is quite easy, through even so small a bony defect, with a continuous suture placed with a $\frac{3}{8}$", half-curved Lane cleft-palate needle, using a long, curved tonsil hemostat for a needle-holder.

When a bilateral cordotomy is done, muscles are separated from the spinous processes and laminae without disrupting the interspinous ligament. Dura mater is exposed at different levels on the two sides (Fig. 3). When the wound is closed, a few sutures are placed in the deep muscles through the interspinous ligaments. The other tissues are closed with separate layers of interrupted cotton sutures. This technique results in a great deal less post-operative pain in the shoulders and neck than usually follows cervical laminectomy. The patients can be mobilized as early as their general condition permits, making convalescence shorter and less complicated.

SURGICAL TECHNIQUE

The patient is anesthetized with intravenous pentothal sodium solution and the trachea is intubated. He is postured upright as described earlier. The skin of the

neck is prepared and draped. The skin and subjacent tissues are infiltrated to the bone with 1 per cent procaine solution. A vertical skin incision is made from the spinous process of C3 to C6 and muscles are reflected on the side of the cordotomy, from the spinous processes and laminae of C5 and C6. The ligamentous attachments may be removed from additional spinous processes to make retraction easier if required, but no more muscle than necessary is removed from the bone.

With a sharp curette, the lower edge of C5 lamina is cleared of its attached ligamentum flavum. If the upper edge of C6 lamina is easily approachable at this time, it is treated similarly. If not, this is deferred until after the laminotomy of C5. With a straight or angled rongeur, the lower edge of C5 lamina is removed through about one-half of the vertical width of the lamina, laterally as far as possible, and medially almost to the base of the spinous process. Then the upper edge of C6 lamina is removed similarly, until a bone defect about 2.5 cm. × 15 mm. is produced. When the patient is in the sitting position, the wound is irrigated freely during the bone removal, until the raw edges can be waxed, to minimize the likelihood of air entering opened marrow-veins.

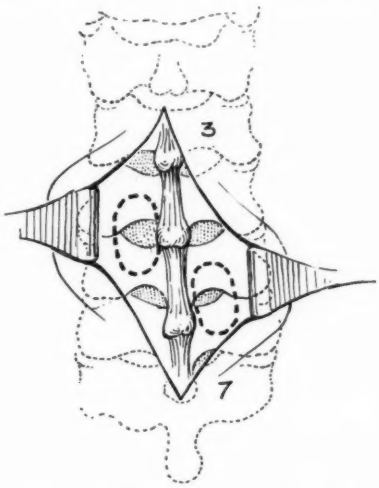

FIG. 3. Location of two laminotomy openings for bilateral cervical cordotomy.

The epidural vessels are lifted with forceps and coagulated gradually until they and the exposed ligamentum flavum are removed. The dura mater is incised vertically. The incision will lie above the attachments of the dorsal rootlets to the cord. Guy sutures separate the dural edges. The lateral suture should be tied into the muscle mass to increase the exposure laterally as much as possible (A, Fig. 4). The arachnoid is opened and fluid drains. The anesthetist is notified, so he can be alert to blood pressure changes. The dentate ligament is grasped with a straight mosquito hemostat and is severed from its dural attachment with a long-handled, small scalpel (B, Fig. 4). As the mosquito forceps is carried medially, the attachment of the dentate ligament to the cord can be seen. Usually a few small blood vessels run vertically along the cord at this site. This is the point for incision into the cord. If it is not easily and accurately demonstrable, a small septal elevator, or some such thin-tipped instrument can be introduced into the dorsal angle between cord and ligament to reveal it.

The knife then is prepared, the blade edge at a right angle to the shaft and directed distally. The tip of the blade is set 6 mm. from the shaft. The handle of the knife is held vertical to the cord. There usually is not enough room between the side of the cord and the dura mater to permit the whole blade length to approach the cord at a right angle, so the blade tip is put on the cord at the dentate angle, with the blade making an acute angle with the cord (B, Fig. 4). The point of the blade is inserted and the shaft is rotated until the blade is directed transversely and is advanced inward to its full 6 mm. length (C, Fig. 4). Using the dentate ligament only

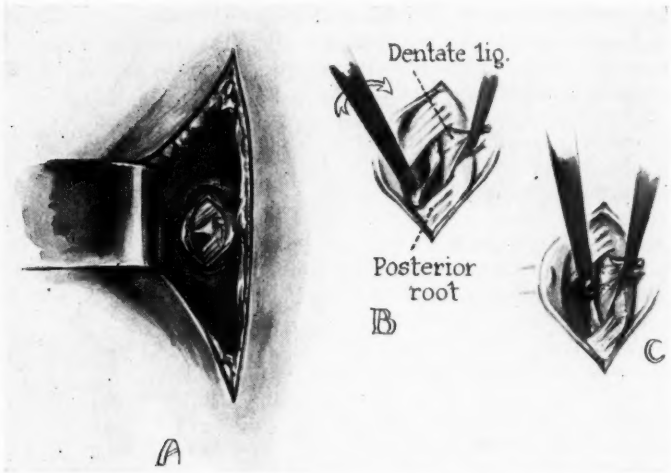

FIG. 4. Stages in the modified left-sided cordotomy operation. (A) Dura mater opened through laminotomy, exposing posterior roots and dentate ligament. (B) Knife point applied at point of penetration. It is advanced to the transverse position by rotation of the shaft. (C) Knife introduced to depth of 6 mm.

for counter-traction to the knife, and with no attempt at rotation of the cord, the knife is passed anteriorly as far as it will go. This is limited by the curvature of the spinal canal (A, Fig. 5). The knife is removed with the same type of rotary motion with which it was introduced. The blade is loosened in the handle and angled 45° downward (B, Fig. 5). It is reinserted into the cord incision and the remainder of the anterolateral quadrant is cut through. To insure denervation of the sacral

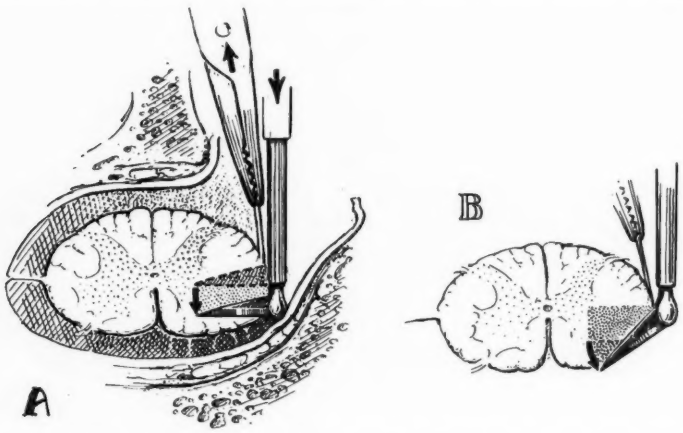

FIG. 5. (A) Anterior thrust of right-angled knife arrested by curvature of spinal canal. (B) Angulated blade position for completing cord incision.

areas, it is important that the incision extend up to or even a little dorsal to the attachment of the dentate ligament. The tip of the blade is thrust through the dentate ligament and into the cord 1–2 mm. dorsal to the point of attachment to the ligament, and is advanced into the previously made cordotomy incision. Some cord bleeding may ensue. In my experience this has always been controllable with Gelfoam®. A split-thickness fragment of wet Gelfoam®, measuring about 4×6 mm., is placed on the concave surface of a septal elevator and is thus applied to the site of the incision. A small strip of cottonoid is placed outside the instrument, which then can be slipped out without displacing the Gelfoam®. Intermittent drying and wetting of the cotton for a few minutes usually results in adhesion of the foam so the cotton can be removed. Any other incidental details of wound toilet are concluded, and the Gelfoam® may then be removed from the cord. Should bleeding follow, a small piece of foam may be left permanently adherent to the cord.

The dura mater then is closed with a continuous locked cotton suture, using a small half-circle needle held in a tonsil hemostat. The exposure is too small for comfortable work with regular dural needles and needle holders. A piece of wet, full thickness Gelfoam® is placed to cover the entire dural exposure. Retractors are removed and the wound is closed in layers with interrupted cotton sutures.

If a bilateral cordotomy is indicated, the second side is done in the same way as the first, but at a higher or lower level.

Because of our experiences[2] with air emboli following operation in the sitting position, these patients are placed on the cart and transported to their rooms in the left lateral decubitus.

SUMMARY

A modification is described for the technique of spinothalamic cordotomy.

The technique was devised to permit cordotomy without rotation of the spinal cord.

The operation is done through minimal laminotomy openings in a shorter time and, it is believed, with less shock and with more precision than attend the standard operation.

The sequelae of the incision are sufficiently predictable that the operation can be done under general anesthesia without the necessity of sensory testing in the operating room.

I am grateful to Mr. James N. DeSerio, Consulting Engineer, of Buffalo, for review of the physics involved in the discussion of rotation of the spinal cord.

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DELAYED BRAIN ABSCESS IN RELATION TO RETAINED INTRACRANIAL FOREIGN BODIES

JOHN H. DREW, M.D., AND CHARLES A. FAGER, M.D.*
Neurosurgical Service, Boston Veterans Administration Hospital, Boston, Massachusetts

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THE late development of brain abscess around a retained foreign body may be a tragic occurrence. The damage from the abscess itself is superimposed on an already extensively damaged and scarred brain. Normal defense barriers are altered by changes in cerebral architecture and even though the patient survives, the functional loss is almost certain to be greater than in the case of a primary abscess or wound at a similar site.

Cushing,[4,5] in his papers dealing with war wounds, insisted on thorough cleansing of the wound tract. He believed, however, that removal of deeply embedded foreign bodies should not be done at the risk of materially increasing damage already present. Studies carried out immediately after the first World War[13,19] showed that late sequelae, including delayed brain abscess, were less common than anticipated. In World War II adherence to the same surgical principles, combined with antibiotic treatment, significantly reduced mortality, morbidity and eventual permanent disability resulting from such injuries.

The following 2 case histories raise the question of how much or how little should be done at the time of the original injury. These patients' abscesses formed at 6- and 7-year intervals about metallic shell fragments.

Case 1. F.R., 31 years old, sustained a penetrating right frontoparietal wound during combat in 1942. He improved so that by 1944 he walked with a slight limp but had considerable weakness and clumsiness of the left hand. He was admitted to the Cushing Veterans Administration Hospital on Dec. 23, 1949, with a 4-day history of progressive drowsiness and right-sided head pain.

Examination. The patient was lethargic; his neck was stiff and there was marked tenderness over an obvious right parietal skull defect. His temperature was 98.4°F., pulse 84, and B.P. 124/80. He had left hemiparesis and hemihypalgesia. All reflexes were decreased; no pathological reflexes could be elicited. The optic discs and cranial nerves were normal.

Blood count showed 27,650 WBC/c.mm., 96 per cent neutrophils. Spinal fluid pressure was 420 mm. of water. The spinal fluid was slightly turbid and contained 275 WBC/c.mm., 40 per cent lymphocytes and 60 per cent neutrophils; total protein 160 mg. per cent.

Plain x-rays of the skull showed a retained metallic fragment in the parietal

* Present address: Department of Neurosurgery, Lahey Clinic, Boston, Massachusetts.

region on the right side just under the posterior margin of a defect in the bone (Fig. 1).

Hospital Course. About 8 hours after admission the patient became irrational and more lethargic. The CSF at that time contained 15,500 WBC/c.mm., with 95 per cent neutrophils; total protein 800 mg. per cent. A smear of the fluid showed gram positive cocci. A small amount of purulent drainage appeared from the old scar overlying the cranial defect.

Operation. The patient was immediately taken to the operating room where a parietal incision was made beginning at the point of drainage. This exposed a large, deep, subdural (subgaleal?) abscess with a sinus tract arising beneath the posterior margin of the skull defect. About 3.5 cm. behind the edge of the bone, within the

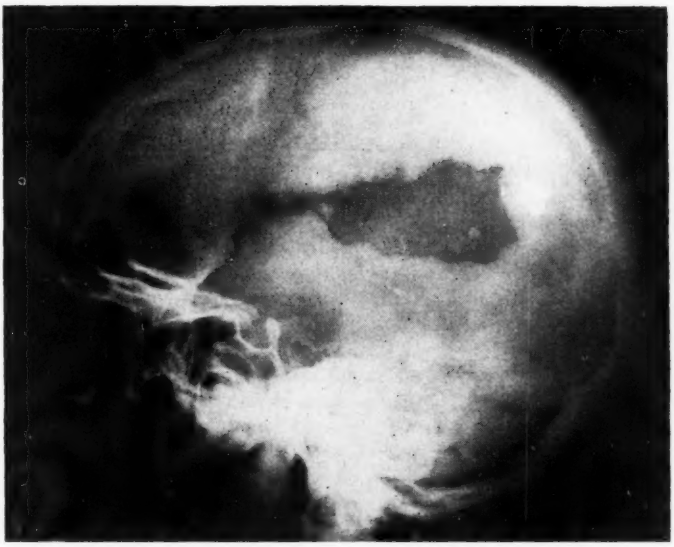

FIG. 1. *Case 1.* X-ray showing frontoparietal defect with shrapnel fragment just under and behind posterior margin of the defect.

abscess cavity, the metallic fragment was found, covered by a pyogenic membrane. The abscess itself had ruptured into a large porencephalic cyst which communicated with the right lateral ventricle. There was an opening into the ventricle about 1.5 cm. in diameter. The foreign body was removed and the entire area was irrigated with large amounts of solution containing 1,000 U of penicillin per cc. A rubber tissue drain and catheter were left within the cavity.

The infective organism was cultured as Staphylococcus aureus.

Postoperative Course. Intensive treatment was started with antibiotics, chemotherapy and local irrigations of penicillin solution. The patient improved steadily and the spinal fluid remained sterile. The CSF protein then gradually increased and on Jan. 4, 1950, the CSF pressure was 280 mm. of water; total protein was 1,180 mg. per cent. The patient's condition gradually deteriorated, and although the lumbar CSF pressure returned to normal there was a steady rise in protein to 3,350 mg. per cent. He expired on Jan. 29, 1950.

Autopsy. There was extensive basal arachnoiditis, with obliteration of basal cisterns by dense adhesions, and a cerebellar pressure cone. A porencephalic cyst communicated with the occipital horn of the right lateral ventricle. The abscess had not recurred.

Comment. In this patient the abscess presumably had formed around the retained shell fragment, and then ruptured into the large porencephalic cyst which certainly must have been the result of the initial injury. The basal arachnoiditis found at autopsy was secondary to rupture of the abscess into the ventricle. The initial trauma provided a foreign body, local brain damage with tissue destruction, scar formation and a porencephalic cyst. The thin wall of the cyst was all that separated the abscess from the ventricle—and this only temporarily. This particular foreign body was easily accessible and probably should have been removed at the time of injury or as soon thereafter as his condition would permit.

Case 2. J.C., a 28-year-old laborer, was admitted to the Cushing Veterans Administration Hospital on Oct. 31, 1950, complaining of headache for 1 month. During that time he was reported as having been lethargic, indifferent and careless in his dress and personal habits. In 1944 he had sustained a penetrating shrapnel wound of the right hemisphere followed by left hemiplegia. This had gradually improved leaving a slight residual left hemiparesis which did not interfere with his work as a laborer. In 1946 a tantalum plate was inserted over the right fronto-temporo-parietal defect.

Examination. Temperature was 98.6°F., pulse 80, respiratory rate 20, and B.P. 100/60. He complained of severe headache, appeared drowsy and responded slowly. There was no tenderness over the plated area on the right side of the head. He had a slight residual left hemiparesis with increased deep tendon reflexes on the left and a left Babinski sign. Stereognosis was diminished in the left hand and there was slight left hemihypalgesia. He had a left homonymous hemianopia; there was no papilledema. The rest of the cranial nerves were unaffected.

Blood and urine were normal. Initial CSF pressure was 170 mm. of water. The fluid was clear and colorless but contained 18 lymphocytes; total protein was 165 mg. per cent.

Plain x-rays of the skull showed a large plate overlying the right-sided skull defect and, in addition, a metallic foreign body lying in the inferior portion of the *left* frontal lobe, indicating the probable path of the penetrating missile (Fig. 2).

Hospital Course. Two days after admission the patient's condition showed no essential change. On the 3rd day his temperature rose to 102°F. and he became less responsive. The CSF pressure was 260 mm. of water and the fluid contained 86 lymphocytes. The patient rapidly lapsed into coma with both pupils dilated and fixed. His respirations became shallow and irregular and ventriculography performed immediately indicated a mass lesion in the *left* frontal lobe.

1st Operation. A left frontal craniotomy was immediately carried out, exposing a thin, tense, fluctuant cortex overlying a poorly encapsulated abscess. Because of the patient's poor condition drainage of the abscess was instituted and intensive antibiotic therapy was begun by all available routes.

Course. Repeated smears and cultures of abscess drainage and spinal fluid were sterile. The patient's condition improved slightly but he did not regain consciousness.

Exploration of the abscess site with a needle gave evidence of either recurrence or loculation of the abscess.

2nd Operation. A second craniotomy was performed 12 days after the first. The left frontal lobe including the original abscess wall with the metallic foreign body and a smaller, posteriorly placed abscess were removed.

Course. There was no improvement and the patient slowly passed into a state of decerebrate rigidity. He expired April 19, 1951. Permission for autopsy was not granted.

Comment. Clinical evaluation of this case was difficult because of the neurologic residua from the original injury and the lack of new localizing signs. Abscess formation began around the metallic fragment and extended throughout most of the left frontal lobe. Death was presumably caused by debility and bronchopneumonia following midbrain damage. The single piece of metal which acted as a foreign body was so placed as to be relatively inaccessible when the wound was first debrided and it is questionable whether any attempt at later elective removal would have been justified.

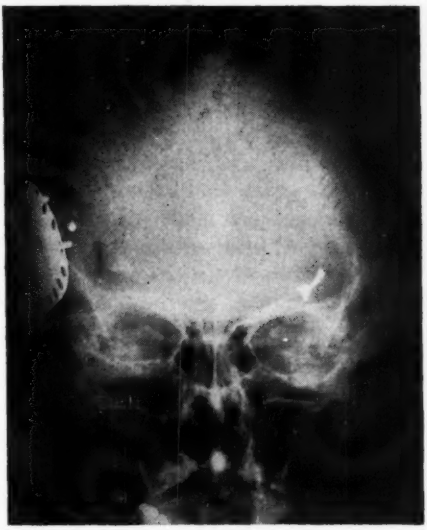

FIG. 2. *Case 2.* X-ray and ventriculogram showing metallic foreign body in left frontal region far removed from apparent site of injury indicated by tantalum plate on right.

DISCUSSION

Abscess formation in relation to a retained foreign body is most likely to occur during the early weeks following injury but it is well known that the free interval may be quite long. Grant[9] said, "A patient who has had a penetrating brain wound and apparently been in perfect health for a number of years may suddenly develop an intense headache, become rapidly stuporous and die within twenty-four hours from rupture of a latent abscess into the ventricle and fulminating meningitis." In his collective review of brain abscess,[8] he summarized observations that had been made since 1918 and concluded that brain abscess rarely follows head injury unless the dura mater is penetrated; that metallic foreign bodies are better tolerated than bone fragments; and that in patients with intracranial inclusions an abscess may develop about the source as late as 20 years after the injury. The longest case on record appears to be that of Nauwerck[15] whose patient had attempted suicide in 1878. A retained revolver bullet within the left frontal lobe caused him no trouble until 1916, 38 years later, when a fatal brain abscess developed. Another case, reported in 1881,[14] is that of a patient in whom a locu-

lated cerebral abscess developed 27 years after injury. Autopsy showed bony spicules 8 mm. long on the inner table of the skull but no mention was made of whether or not they penetrated the dura mater.

Oppenheim[16] and other authors have referred to these cases as evidence that the interval following trauma can be as long as 10 to 30 years. Wilson[21] and Oppenheim[16] stressed the point that so many years may elapse after the initial trauma that the incident may have been forgotten when the symptoms of abscess appear. King[11] has reported a patient who unknowingly carried a knife blade in his head for 28 years. Several months after the blade was removed an abscess developed. Alajouanine, Maisonnet and Petit-Dutaillis[1] in 1928 noted 56 cases of brain abscess occurring during the first year following injury and 16 more than a year afterward. This study further emphasizes the fact that late brain abscesses are not a rarity—although no statement was made as to how many of these patients had retained foreign bodies.

There is general agreement that retained free bone fragments are more likely to cause brain abscesses than are those of metal.[9] This is true of both acute and delayed lesions. However, acute abscess is more likely to develop around bone[6] while a late abscess is most often secondary to a bit of metal (although one of Cairns and Donald's[3] patients went 19 years before an abscess developed around a piece of bone). Retained bone was responsible for abscess formation within 6 weeks in 25 per cent of Rowe and Turner's[17] patients. And Martin and Campbell[13] found infection to be ten times more frequent around bone fragments than in their absence. Certainly early abscesses occur both in patients with retained bone or metal fragments.[12] Because this early incidence is greater with retained bone, there are few of these patients in the late group. All patients with retained foreign bodies, whether bone or metal, must be considered as "suspects" and regarded as potential chronic abscess carriers. Any increase in neurologic deficit or suggestion of intracranial infection in such a patient should be viewed with suspicion, if not alarm, and every effort should be made to determine the possible presence of an intracranial abscess, regardless of the length of the latent period after injury. In this respect, baseline angiograms may be of value as well as plain x-rays of the skull to check on shift of position of the metallic or bone fragments. Four of Wood's[22] 40 patients having retained metallic fragments showed such change in position in the presence of abscess. If air contrast studies are made before the patient leaves the hospital following initial injury,[2] these may be used for comparison at a later date, although if repeated in the presence of abscess there is the ever-present danger of rupture into the ventricular system.

Why a nidus of infection should remain latent for years without signs or symptoms, then suddenly flare up to become an active process leading to brain abscess is an unsolved and speculative problem. The organisms present at any site of injury or tissue destruction may be of low initial virulence and so succumb readily to natural body-defense mechanisms. If this does not

result in complete elimination of infection with cure, the focus may remain for many years as a small, completely inactive abscess.[3] Or, with modern chemotherapy and antibiotics, the original infection may be inadequately (or "adequately") treated, the result being that virulence of the organisms is decreased but viability is maintained.

Such situations may exist whether a foreign body is present or not.[12] However, the presence of a bone or metal fragment adds to the probability of lighting up a dormant and asymptomatic focus. Grant[9] states that an acute infection or a debilitating disease may cause these organisms to assume increased virulence. Goldstein[7] wrote in 1925 that too early plating of cranial defects predisposed to abscess formation. White[20] in reviewing 151 late complications of cranioplasty referred to 4 cases of delayed brain abscess under plates. He set 6 months as the minimal time to plate a cranial defect after initial infection and suggested an even longer interval if organisms are penicillin-resistant. Swinburne[18] also mentioned premature plastic procedures as a possible precipitating cause of such abscesses and, as did King,[11] further suggested that a blow on the head may be a contributing factor.

Some evidence that bacteria may lie dormant for long periods is suggested by 2 of Ecker's[6] cases. These patients were asymptomatic with well-healed wounds and normal spinal fluid yet viable organisms were recovered from the brain. Retained bone fragments were present in both patients. The posttraumatic interval was not stated although the maximum period for the entire series was only 86 days. It may be that if a focus of low-grade chronic infection exists new organisms brought to the area, though not of sufficient virulence themselves to cause active infection, may take on a new virulence or cause that of the original organisms to increase.

Another possibility is that tissue around a retained foreign body may be in a state of decreased resistance to infection. Casual bacteria in the blood stream, lodging at such a point, would ordinarily be overcome by normal body-defense mechanisms. However, because of the lowered local resistance, abscess formation may occur. Hematoma has been mentioned in this regard by Swinburne.[18]

No matter how carefully and completely debridement may have been carried out there is extensive, relatively avascular scar formation surrounding the wound tract. If an abscess then forms adjacent to a retained foreign body lying in some part of this scar, the ease and speed with which it extends and spreads will theoretically be much greater in the scarred area than in the normal brain. Assuming that such a *locus minoris resistentiae* plays a part in the development of brain abscess in relation to foreign bodies, the tissue along the tract of the missile must be considered as fertile ground for the growth of such an abscess once it has begun to develop. Large abscesses may form rapidly in the damaged brain and then spread to adjacent normal tissue.

The fact that there are today many patients who harbor metallic or even bony fragments in the brain without any ill effects clearly illustrates

that a policy of close observation with alertness to any change in the patient's condition is warranted in all or nearly all cases. By presenting these cases of long-delayed brain abscesses formed in the presence of foreign bodies, we certainly do not advocate the wholesale removal of such objects in the absence of progressive signs and symptoms. Nor do we suggest violation of the principles of early debridement as noted above. Delayed abscesses are infrequent, although not rare, and to regard watchful waiting as a calculated risk is justifiable. A possible exception might be a situation such as that presented in Case 1, in which the foreign body was easily accessible in a non-vital area.

SUMMARY

Two cases of long-delayed (6–7 years) brain abscess formation at the site of retained foreign bodies are reported in detail. Because of superimposition of brain damage in an already injured area, patients who survive such lesions are liable to be much more severely crippled neurologically than those with primary abscesses in the same region.

The true pathogenesis of such lesions is unknown. The possibility that these abscesses may be caused by a latent or new infection in a damaged area of low resistance is considered. Various possible precipitating causes such as cranial trauma, acute infectious or debilitating diseases have been suggested. In many cases there is no apparent reason for the development of an abscess at a particular moment.

Prompt and adequate debridement and antibiotic therapy at the time of injury will help to prevent these lesions. Their relative infrequency contraindicates radical surgical procedures for foreign body removal in the absence of progressive signs and symptoms. However, once progress is established every reasonable attempt should be made to determine the presence of infection. Such infection must then be treated vigorously with every effort being made to minimize brain damage.

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CASE REPORTS AND TECHNICAL NOTE

NOCARDIOSIS WITH MULTILOCULAR CEREBELLAR ABSCESS

REPORT OF A CURED CASE

C. F. List, M.D.,* J. R. Williams, M.D., C. B. Beeman, M.D., and C. A. Payne, M.D.
Grand Rapids, Michigan

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Nocardia is an aerobic, partially acid-fast actinomycete, pathogenic to man and animals.[3] The name "Nocardia" was given in memory of Nocard who in 1888 discovered this organism as the cause of bovine farcy. There are various subspecies of Nocardia, the most common being Nocardia asteroides—also known under the synonyms Cladothrix asteroides, Streptothrix eppingeri, Oospora asteroides, and Actinomyces asteroides.

Even though this organism is a ubiquitous inhabitant of the soil, human nocardiosis appears to be a remarkably rare disease and records of only 54 such cases were found in the literature.[1,2,4–10,12,14] The primary lesion is usually found in the lungs and bronchopulmonary lymph nodes, occasionally in the subcutaneous tissues (as the result of accidental penetrating injury), or in the gastrointestinal tract.[7] The infection then spreads by the hematogenous route and frequently produces metastatic intracranial lesions, notably brain abscesses. Among the 54 recorded cases there was proven intracranial involvement in at least 17 cases. The mortality rate of human nocardiosis is high; so far only one instance is known of cured intracranial Nocardia infection.† In this case, described by Jacobson and Cloward,[8] a 28-year-old psychotic Japanese woman was proved to have meningitis caused by Nocardia asteroides. The patient recovered after being treated with large doses of sulfadiazine and intramuscular and intrathecal injections of penicillin and streptomycin, combined with ventricular drainage.

Facing the almost hopeless prognosis of intracranial nocardiosis, additional experiences must be gathered and it therefore appears worth while to record any further case of successful treatment. In the following we wish to describe in detail a case of nocardiosis with multilocular cerebellar abscess, terminating in recovery.

#51-446. W. van S., a 48-year-old bread salesman, was admitted to Blodgett Memorial Hospital, Grand Rapids, Michigan, on Jan. 20, 1951. Approximately 10 weeks previously, he had begun to complain of general lassitude, and pain in the left shoulder and epigastrium. The condition of his shoulder was diagnosed as calcifying bursitis and was treated by roentgen irradiation and aspiration. The epigastric pain, which occurred chiefly on fasting, was relieved by ingestion of food and antispasmodic drugs. Eight weeks prior to admission, a persistent hacking cough developed, productive of scanty, nonhemorrhagic, nonpurulent sputum.

* 833 Lake Drive, S.E., Grand Rapids, 6, Michigan.

† Since this paper was submitted for publication another case of successful treatment of cerebral nocardial infection has been reported (Krueger, E. G., Norsa, L., Kenney, M., and Price, P. A. Nocardiosis of the central nervous system. *J. Neurosurg.*, 1954, *11:* 226–233).

There was no fever. Roentgenograms of the chest revealed infiltrative lesions in both lower lung fields, supposedly virus pneumonia. After unsuccessful treatment with penicillin and aureomycin for 16 days, bronchoscopy was performed but this procedure yielded no further information. Thereafter, his general condition deteriorated; he complained of nucho-occipital and frontotemporal headaches, nausea and, finally, of failing vision.

Examination. The patient appeared chronically ill, irritable and anxious. Temperature was 98.6°, pulse rate 84, respiratory rate 18, and B.P. 136/80. Physical examination of the chest revealed no abnormal findings. There was slight epigastric tenderness. The prostate gland was moderately enlarged without signs of malignancy. The left shoulder was "frozen" because of previous bursitis. Neurologic findings were not remarkable.

Urine was normal. RBC 4,380,000, WBC 6,650, Hb. 13.3 gm.—86 per cent, eosinoph. 1, stabs 2, segment 85, lymphs 12. Blood Kahn negative. Serum albumin 3.76; globulin 2.74. Blood N.P.N. 27; fasting blood sugar 129.

Roentgenograms of the chest showed an infiltration in the left lung at the level of the 5th rib near the heart. The left hilar shadow was enlarged. The right lung was normal.

The sputum contained no acid-fast organisms but on culture there was heavy growth of Streptococcus viridans and scanty growth of Staphylococcus aureus and nonpathogenic yeasts.

Roentgenograms of the upper gastrointestinal tract disclosed a peculiar rugal pattern compatible with the diagnosis of gastritis or duodenitis. The duodenal bulb was deformed suggesting ulcer (or prolapsed gastric mucosa?). On the cholecystogram there were areas of decreased density, suggestive of gallstones.

Course. At this state of the investigation no definite diagnosis could be made. It was felt that the gastrointestinal findings were probably unrelated to the pulmonary lesion, the anatomic nature of which remained obscure; the possibility of a primary bronchogenic carcinoma was considered. In the 10 days following admission, new and progressive symptoms appeared pointing to a lesion of the central nervous system. He became increasingly lethargic, depressed and refused to eat. Urinary retention occurred on several occasions. Nucho-occipital headaches and nausea were frequent and at times associated with vomiting. Finally, his pulse rate dropped to 50–60 per min.

Lumbar puncture revealed an initial pressure of 150 mm. of H_2O. The fluid was clear, colorless, and contained 1 lymphocyte; total protein 114 mg., sugar 76.9, gold curve and Kahn negative.

Neurosurgical consultation was then obtained. The emaciated patient was conscious but lethargic, indifferent and without psychomotor initiative. The right suboccipital region was tender to pressure and the neck was moderately rigid. There was mild paresis of the left 6th nerve with marked horizontal nystagmus to the left, less to right, and slight vertical nystagmus upwards. Pupils, fundi and fields were normal. A slight left lower facial weakness was noted. There was generalized hypotonicity, especially in the left arm and leg. The left extremities exhibited mild paresis, kinetic ataxia, dysmetria and slowing of diadokokinesis. When attempting to sit he fell asynergically to the right and backwards. There was bilateral positive Babinski sign. All other reflexes were normal. Sensory changes could not be demonstrated.

Detailed EEG study revealed numerous bursts of high voltage 1 to 2 per sec. delta waves occurring bilaterally, especially in the frontal, parietal and temporal areas, and with greater emphasis on the right side. These findings indicated either a diffuse degenerative process or a deep cerebral focal lesion. It was suggested that if the lesion was in the posterior fossa it would more likely be on the left side. Roentgenograms of the skull showed slight displacement of the calcified pineal shadow to the left.

Reviewing the case in the light of the neurologic findings, it was now assumed that the patient had multiple expanding intracranial lesions, with a large mass in the left cerebellum and possibly additional lesions in the cerebral hemispheres. Intracranial metastases from bronchogenic carcinoma appeared to be the most likely diagnosis, yet metastatic intracranial granuloma could not be ruled out. Intracranial abscess was considered improbable because of the absence of fever and of inflammatory reaction in blood and spinal fluid.

Operation, Feb. 3, 1951. Ventriculography demonstrated considerable symmetrical enlargement of the lateral ventricles and 3rd ventricle. The aqueduct and proximal portion of the 4th ventricle were angulated forward and displaced to the right. The ventricular fluid contained no cells and only 5 mg. per cent protein. The presence of an expanding mass in the left cerebellar hemisphere was thus confirmed but any sizeable supratentorial mass was ruled out.

Immediate left suboccipital craniectomy was done under local anesthesia. On exploratory tap of the left cerebellar hemisphere, firm resistance was encountered at a depth of 2 cm., and a little deeper, an abscess cavity was entered, yielding yellow pus. After uncapping the overlying cerebellum, the thin friable capsule of the abscess was exposed; it broke during dissection, spilling 25 cc. of pus. No sooner had the wall of the abscess been removed than another smaller abscess was brought into view and then excised. A cluster of four additional smaller abscesses embedded in thick avascular fibrous granulation tissue was removed—the deepest of these was the size of a hazelnut and had the thickest capsule. Thus all pathologic tissue was resected except a few indurated areas at the dorsal surface of the cerebellum. The multilocular abscess had occupied the entire dorsolateral part of the left cerebellar hemisphere and extended almost to the incisura tentorii. The wound was tightly closed after instilling an aqueous solution of 100,000 U penicillin into the operative cavity and another 25,000 U into the lateral ventricle.

From the day of surgery the patient was given 2,400,000 U aqueous penicillin and 2 gm. dihydrostreptomycin daily, but on the 2nd postoperative day the dose of penicillin was increased to 4,800,000 U.

Bacteriological Studies. Direct smear of the pus revealed no organisms. Culture on blood agar and Sabouraud's media revealed a large chalky white, aerobic colony after 10 days' incubation. It was composed of gram-positive, nonacid-fast mycelia and was classified tentatively as Nocardia asteroides. Guinea pig innoculation on two occasions failed to produce lesions. The organism was submitted to three other mycological laboratories; two reported it was typical of Nocardia asteroides and one felt it probably was Nocardia asteroides. This organism was inhibited in vitro by no less than 10 U of penicillin. Chloromycetin also was slightly inhibitory but terramycin, aureomycin and bacitracin were ineffective.

Histologic examination of the tissue removed at operation revealed multiple foci of suppuration in the parenchyma of the brain. Some were recent and other larger foci had a peripheral zone of fibroblastic proliferation forming a definite wall and replacing parenchyma of the brain. Polymorphonuclear leucocytes predominated but were mixed with lymphocytes, and a few plasma cells and eosinophiles. Granules were not seen but a McManus stain (PAS) revealed groups of gram-positive hyphae and mycelia interlacing between groups of leucocytes. Other organisms were neither seen nor cultured from the material.

Course. The patient had not only tolerated the operation well but showed immediate and progressive improvement. His sensorium cleared, temperature remained normal and signs of meningeal irritation did not develop. In an effort to achieve an optimal blood level, the dose of penicillin was doubled (9,600,000 U daily) and sulfadiazine was added in doses of 6 gm. daily; dihydrostreptomycin was discontinued after 1 week. Actually the minimum blood level of penicillin was maintained at 10 U/cc. and that of sulfadiazine was 15 mg. per cent. Under this management the patient continued to improve. He became alert and accessible, yet relapsed occasionally into a confused state. The cerebellar syndrome receded, especially in the lower extremity. The incision healed well.

He was discharged to a local hospital in Grand Haven, Michigan, on the 15th postoperative day, where the same doses of penicillin and sulfadiazine were administered for 8 additional weeks. In total he had been given 643.2 million U of penicillin and 414 gm. of sulfadiazine in 72 days; furthermore, he had received 15 gm. of dihydrostreptomycin in 8 days.

When last seen in November 1953, 2 years and 9 months postoperatively, he had no complaints referable to his nervous system and led a normal life. He had gained 20 lbs. in weight. He appeared to be mentally normal. There were still mild residual cerebellar signs in the left upper extremity and some periarthritic stiffening of the left shoulder. Chest x-rays were normal. Complete blood count, urinalysis and sedimentation rate were normal.

COMMENT

Even though the exact nature of the pulmonary lesion was not verified in our observation, it is reasonable to assume that it was a pneumonitis caused by Nocardia and probably represented the primary focus of infection. From reports of the literature one gains the impression that the pulmonary lesions, unless too far advanced, respond more readily to treatment than the cerebral lesions.

The intracranial manifestations of nocardiosis tend to be multiple because of their metastatic origin. In the early stage, purulent metastatic encephalitis develops, followed by encapsulated brain abscesses. In some of the recorded cases, including our own, the inflammatory meningeal reaction was surprisingly slight or even absent. In others, such as in the observation of Jacobson and Cloward, frank meningitis dominated the picture. The fact that the ventriculogram of their patient was normal in the presence of meningitis, may suggest associated brain swelling caused by encephalitic involvement. In more chronic lesions there is tissue necrosis, and abscess formation with surrounding nonspecific granulomatous inflammation (without epithelioid or giant cells). Multiplicity and dissemination of the abscesses account for some of the therapeutic failures, and conversely, the favorable outcome in our own case may be attributed to the circumscribed character of the lesions.

At present, the diagnosis of nocardiosis cannot be made by clinical or roentgenologic means, yet it should be suspected if a chronic infectious state is associated with lymphadenopathy, and pulmonary and cerebral lesions. If, however, as in our case, the signs of general systemic infection are minimal, the differential diagnosis against bronchogenic carcinoma with cerebral metastases must be considered.

Laboratory identification of the Nocardia species is relatively simple although proof of pathogenicity is sometimes difficult. The branching filamentous organisms are aerobic, gram-positive, partially acid-fast or nonacid-fast. They require 2–3 weeks to develop a typical colony, but grow readily at 37°C. or room temperature on a variety of simple media, including Sabouraud's glucose agar and beef infusion glucose agar. The colonies are usually glabrous, wrinkled or granular and tough. Occasional strains produce aerial mycelia giving a powdery or chalky appearance to the colony. Most species of Nocardia are mere saprophytes, but Nocardia asteroides is pathogenic to laboratory animals and man, yet the degree of pathogenicity is variable. Intravenous injections in rabbits usually produce miliary abscesses in many organs whereas intramuscular or subcutaneous injections produce only local abscesses.

Successful treatment of cerebral Nocardia infection requires surgical removal of the focus (or foci) and extremely vigorous and prolonged chemotherapeutic and antibiotic treatment. Surgical management of a nocardial abscess differs little from that of other brain abscesses. The lesion should be radically excised; simple drainage is ineffective because of the multilocular character of the abscesses and the prolific growth of the organisms. Total excision may be admittedly impossible in the presence of multiple abscesses. At the time of operation the diagnosis of Nocardia is, as a rule, not yet made. It is therefore advisable to instill a suitable antibiotic solution into the operative site and into the ventricle in order to control other bacterial invaders.

Effective medical treatment requires determination of the drug sensitivity of the organisms. Sensitivity studies in vitro are valuable but do not necessarily permit one to predict the therapeutic effect in vivo. Runyon,[11] and Strauss, Kligman and Pillsbury[13] investigated experimentally pathogenicity and drug sensitivity of Nocardia asteroides. These authors found that the organism is inhibited in vitro by sulfa-

diazine, aureomycin and myvizon, and to a lesser extent by chloromycetin and streptomycin. Penicillin, on the other hand, had only minimal inhibitory effect or none at all, unless given in extremely high doses.

In vivo (by means of animal protection tests), sulfadiazine again proved to be the most effective drug, whereas aureomycin and myvizon gave only limited protection. Clinical experiences with the treatment of nocardiosis have been so far too limited in number for conclusive evaluation; moreover, in most cases, several drugs have been used in combination. All authors agree, however, that sulfadiazine is effective and should be given in large doses over a long period. The opinions about penicillin are divided; most investigators consider it ineffective, yet in some of the recorded cases Nocardia was quite susceptible to this drug (e.g. in the case of Hager, Migliaccio and Young[6]). In our own observation the sensitivity ratio was low, i.e. no less than 10 U of penicillin/cc. were needed to inhibit the growth of the organism. The different strains of Nocardia probably vary in their penicillin sensitivity. A similar situation obtains for aureomycin and streptomycin.

From these observations one can draw only one practical conclusion, viz. sulfadiazine must be given in combination with appropriate antibiotics in high doses over a long time. If penicillin is used, it should be administered in sufficiently large amounts to attain an effective blood level, i.e. a drug concentration that inhibits the organism in vitro. This was accomplished in our case by a daily dose of 9,600,000 U of penicillin. Although Nocardia may be sensitive to streptomycin, prolonged use of this drug is undesirable because of its adverse side effects (on the 8th nerve).

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ACTINOMYCOTIC (NOCARDIA ASTEROIDES) BRAIN ABSCESS WITH RECOVERY

CASE REPORT*

RALPH A. MUNSLOW, M.D.†
San Antonio, Texas

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The widespread use of antibiotics has materially reduced the incidence of brain abscess within the past decade. This has been particularly true of those abscesses occurring as a consequence of otitic and sinus infections of bacterial origin. In a group of 10 brain abscesses observed during the past few years, 2 were caused by fungi. Though one of the two latter patients died, an apparent cure has been effected in the other with the use of antibiotics and surgical excision. This is believed to be the fourth reported recovery of a patient with actinomycotic brain abscess.

Ponfick,[5] in 1880, first described actinomycosis of the brain. Ten years later Eppinger[2] made the first report of a brain abscess caused by Nocardia asteroides. Friedman and Levy[3] were able to collect 108 reported cases of actinomycosis involving the central nervous system by 1937 but found the results universally fatal. Eleven years later Jacobson and Cloward[4] described the recovery of a patient with actinomycotic meningitis through the use of penicillin and sulphadiazine. The first cure of actinomycotic brain abscess, however, was reported in 1949 by Schneider and Rand;[6] the lesion was apparently thoracogenic and was excised during intensive antibiotic and sulpha therapy. Tinsley and Froman[8] recorded the second recovery; in their case the brain abscess was also secondary to pleuropulmonary actinomycosis. In a comprehensive review of the problem published in 1953, Stevens[7] described the third instance of successful management of these abscesses by excision.

A few years ago a middle-aged farmer's wife was seen in consultation because of profound coma and left hemiparesis.[1] One and one-half years previously headaches of increasing frequency and severity began soon after tooth extraction. Jacksonian seizures were noted 1 month prior to hospitalization. Despite no evidence of systemic infection, brain abscess was suspected. Ventriculography confirmed the neurologic impression of right frontal localization and approximately 1 ounce of pus was obtained when the abscess was tapped. The patient, however, failed to respond and at autopsy it was apparent that pus had been obtained only from the original thick-walled abscess, the adjacent daughter abscess containing three times that amount of purulent material. Nocardia asteroides was isolated from the pus. It was felt the portal of entry was the tooth socket and that rupture of the chronic, thick-walled abscess coincided clinically and pathologically with acute onset of symptoms 1 month prior to admission.

CASE REPORT

In March 1952, H. M., a 22-year-old Latin-American boy, was referred because of "fits" which the usual anticonvulsant drugs had failed to control. Except for chronic drainage from the left ear of unknown duration, the patient had been well until 7 months previously when he began to have morning headaches and infrequent seizures. It was believed that the sei-

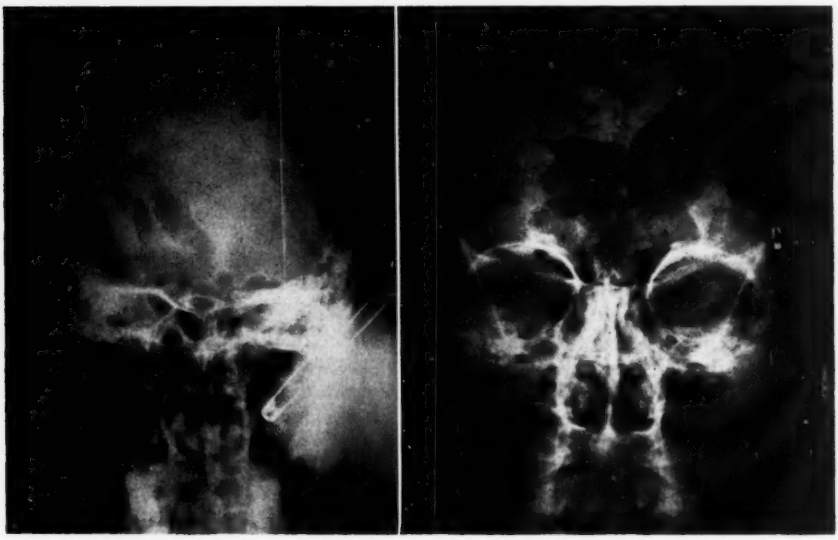
* Read before Southern Neurosurgical Society, Baltimore, Maryland, January 29, 1954.

† 1233 Nix Professional Bldg., San Antonio 5, Texas.

zures began in the right face, spreading to the right arm and leg before becoming generalized. One month prior to admission headaches increased in severity and were followed by drowsiness and ptosis of the left eyelid. Two days before admission and after a generalized convulsion, the patient noted he was unable to move the left eye or lid.

Examination. The patient was too lethargic to cooperate for adequate testing. In addition to left external ophthalmoplegia, bilateral papilledema of 4 to 5 D. and retinal hemorrhages were found. Vision on the left was markedly reduced. The temperature was 99.6°F., pulse rate 70, and respiratory rate 18. X-rays of the skull and chest were normal as were the Wassermann, urinalysis and blood count, except for WBC 12,350 with 73 per cent polys. Ventriculography (Fig. 1) suggested a left frontal mass.

Operation. Through a left frontotemporal flap a thick-walled abscess lying 4 cm. subcortically was tapped, 90 cc. of thick, odorless pus being evacuated. By means of a frontal transcortical incision the abscess was completely excised, after the method of Clovis Vincent. Cerebral swelling prevented replacement of the bone with the flap.



FIGS. 1 and 2. (Left) Ventriculogram (outline retouched) to show displacement by a frontal mass. (*Right*) Postoperative pneumoencephalogram demonstrating left porencephalic cyst.

Pathological Report. Section of the specimen removed at operation revealed a smaller, anterior thick-walled abscess with a contiguous, thin-walled, multiloculated abscess posteriorly. Microscopically (Fig. 3) the abscess wall appeared to be well circumscribed and was surrounded by a zone of moderately edematous brain tissue.

Bacteriological Report. Cultures* from the purulent material within the abscess cavity revealed Nocardia asteroides.

Course. The patient was immediately placed on 400,000 units penicillin with 1 gm. dihydrostreptomycin every 6 hours. After the 2nd postoperative day he was afebrile for the remainder of his convalescence. Right hemiparesis and aphasia began to recede after the 4th day, and vision of the left eye improved. The wound healed per primam and the patient was

* Isolated by Dr. F. W. Bieberdorf, Department of Mycology, Southwest Research Institute and Santa Rosa Hospital.

up and about after a week. On the 12th day bulging of the flap was noted, and pneumoencephalography (Fig. 2) was done to rule out the possibility of multiple abscesses. A porencephalic cyst at the operative site was found, but there was no displacement of the ventricular system. The patient was discharged on his 19th postoperative day, continuing antibiotic therapy with 1,000,000 units penicillin daily by mouth.

When seen 2 months later, the patient presented only reduction of visual acuity. Fifteen months after original surgery tantalum cranioplasty was carried out. No evidence of active infection was evident at this time, and portions of bone, soft tissue, and ventricular fluid submitted for culture were sterile. When last seen, 25 months after excision of the abscess, he had no complaints and remained neurologically negative.

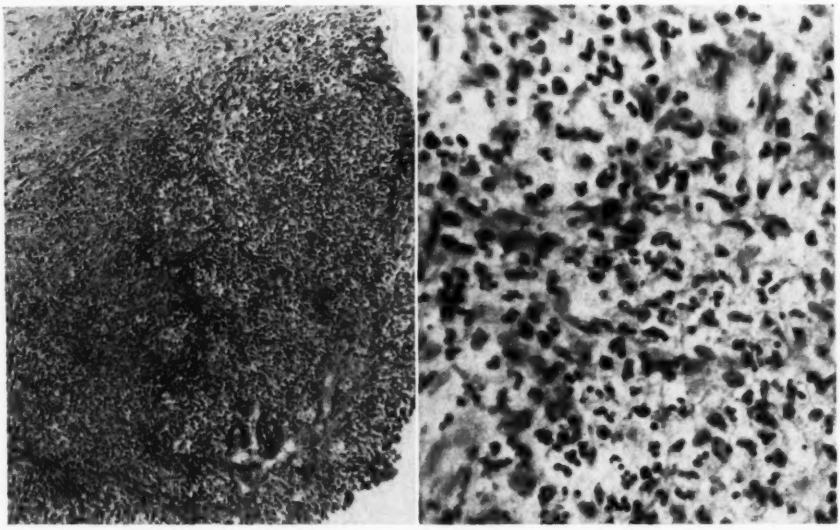


FIG. 3. Photomicrographs. (*Left*) Typical wall of brain abscess. (*Right*) High power view of abscess wall. (Hematoxylin-eosin stain)

DISCUSSION

Stevens[7] has recently stressed the importance of differentiating actinomycosis into those cases caused by Actinomyces bovis and Nocardia asteroides. Whereas Actinomyces bovis is non-acid fast, anaerobic, and not found in vegetable material, Nocardia asteroides is aerobic, partially acid fast, and has been isolated from soil. Man acquires these fungi from unknown exogenous sources. Within the nervous system the morbid changes produced by these two fungi are indistinguishable. Clinically the patient may manifest signs of meningitis, abscess, or both. Rarely an actinomycoma, usually involving the ventricular system, may be found. Stevens calls attention to the characteristic symptomatology of actinomycoses: "The chronicity, sudden appearance of neurologic involvement, remission and exacerbations." The experiences here cited would indeed parallel this clinical course.

In addition to the use of penicillin for actinomycosis, success elsewhere in the body has been described with the use of this drug in combination with Streptomycin and sulphonamides, the latter alone, Aureomycin, Terramycin, and Stilbamidine,

to mention only those most frequently used. Equally important in the treatment of actinomycotic brain abscess is the adequate evacuation of purulent material, once the infection has become localized, either by excision or drainage.

SUMMARY

An apparent cure of actinomycotic brain abscess is described through the use of surgical excision and antibiotics. Nocardia asteroides was the causative organism. The patient remains well 2 years after surgery.

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UNUSUAL RECOVERY FOLLOWING MARKED DISLOCATION OF LUMBAR SPINE

Howard A. Brown, M.D.*
San Francisco, California

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Recovery of function following spinal trauma that involves the cauda equina may often be of marked degree. Operative exploration and decompression of the nerve roots in the lumbar region are frequently indicated following trauma, in contrast to lesions that involve the spinal cord at higher levels.

The reason for reporting the case here presented is to demonstrate that despite excessive deformity and displacement of the vertebral bodies, relatively good recovery may take place, emphasizing the importance of using all possible therapeutic measures in patients with lesions of the cauda equina.

CASE REPORT

The patient, a young woman aged 22, was injured Feb. 7, 1947, in a fall from the front seat of a car when the door flew open while going around a corner. She was temporarily unconscious but upon awakening noted complete paralysis of both lower extremities and severe pain in the lumbar spine. There was also a complete loss of sensation below the waist subjectively.

X-rays taken following the injury showed a very marked lateral displacement of the 1st lumbar laterally on L2, almost the full width of the body. There was also a slight forward displacement of L1.

* 384 Post Street, San Francisco 8, California.

Neurological examination 4 days after the injury revealed a complete flaccid paralysis of both lower extremities and a marked sensory loss below the inguinal region. The sensory loss was not complete. Some sensation was perceived as far down as the 4th lumbar root distribution. Also in the lower sacral region some sensation was present, particularly over the saddle area. There was complete areflexia in the lower extremities. There was no sphincter control.

Spinal puncture revealed a complete block in the spinal canal. The fluid was xanthochromic.

1st Operation. A decompressive laminectomy was done Feb. 12, 1947. The lamina of the inferior portion of D12 and the 1st and 2nd lumbar laminae were removed. There was a laceration of the dura mater on the left side with extrusion of one root filament which was caught in the fracture site at the region of the articular facet on the left. The root was replaced and the dura mater was closed.

Orthopedic consultation during the laminectomy was obtained and an attempt was made

FIG. 1

FIG. 2

to manipulate and effect reduction of the dislocation, but without any improvement of the position of the vertebral bodies.

Course. Following surgery there was a slight gradual improvement in sensation over the lumbar and sacral roots.

Follow-up x-rays taken Mar. 30, 1947, revealed complete over-riding with a displacement of the L2 body upward to a point slightly higher than L1, which had occurred while the patient was flat in bed (Fig. 1).

Skeletal traction was then applied through both femurs with 20 pounds on each leg. Only slight alteration in the position was obtained, as shown in Fig. 2. In view of this fact it was decided to perform another operation.

2nd Operation, May 1, 1947. Inspection of the dural sac revealed it to be making a very sharp turn at the level of the dislocation, but as a result of the decompressive laminectomy the structures had accommodated fairly well and the dura mater was pulsating. No further bone was removed. Fusion was then done, using screws and bone grafts, as shown in Figs. 3 and 4.

FIG. 3

FIG. 4

FIG. 5

Course. Subsequently, the patient showed a gradual improvement in motor function and sensation. In January, 1948, she had regained bladder control, and had no dribbling, urgency or frequency. There was further motor improvement, particularly in the upper leg on both sides. By March, 1949, she was able to get around with braces and was doing her own housework. Bladder and bowel control were good and sexual functions were normal. The chief motor deficit was in the anterior tibial muscle groups on either side. Improving strength allowed her to discard her braces with the exception of some improvised rubber foot-drop supports which she used in preference to the usual standard type.

She was seen again in November, 1953. There still was practically no function in the anterior tibial group. She had fair power in the calves on both sides, and had good quadriceps and hamstring function. Knee reflexes had returned. Ankle jerks remained absent. There was still some sensory loss over the L5 and S1 root distributions primarily. Other sensation was essentially normal, sphincters were entirely normal, and there was no back pain despite her deformity.

Subsequently she obtained employment and at the present time is working regularly as a telephone operator and radio dispatcher. She is able to walk about the latter office without support, but in walking outside she uses short crutches to maintain her balance (Fig. 5).

ARTERIOGRAPHIC DEMONSTRATION OF COLLATERAL CIRCULATION THROUGH OPHTHALMIC ARTERY IN INTERNAL CAROTID ARTERY THROMBOSIS

REPORT OF TWO CASES

ERNEST SACHS, JR., M.D.

Hitchcock Clinic, and Department of Surgery (Neurosurgery), Dartmouth Medical School, Hanover, New Hampshire, and Veterans Administration Center, White River Junction, Vermont

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Thrombosis of the internal carotid artery has gained considerable attention in recent years and is a diagnosis made with increasing frequency. An associated loss of vision in the homolateral eye was observed by Kussmaul,[6] Penzoldt,[7] Guthrie and Mayou,[2] Hunt,[3] King and Langworthy,[5] and many others. The explanation usually accepted for this phenomenon has been inadequacy of blood flow through the ophthalmic artery to the retina because of the proximal thrombosis. Walsh and King[9] felt that homolateral blindness and optic atrophy invariably occurred with spontaneous internal carotid thrombosis. Johnson and Walker,[4] however, found optic atrophy and blindness in only 11 of 107 cases they reviewed. More recently Walsh and Smith[10] have extended their observations on ocular complications of internal carotid thrombosis. This *failure* of blindness to occur in the homolateral eye has also intrigued observers, but the ingenious and excellent work of Elschnig,[1] repeated and extended by Walsh and King[9] themselves, had already suggested the explanation of this phenomenon by virtue of their experimental demonstration, on cadavers, of free collateral circulation between the external carotid and ophthalmic arteries.

Another striking thing about internal carotid thrombosis has been the occasional absence of neurological signs or evidence of massive infarction, even after arteriography has demonstrated complete obstruction of flow of dye into the internal carotid vessel in the neck.

Recent experience with 2 cases has brought to light the fact that in cases of internal carotid thrombosis demonstrable by arteriography, collateral circulation through the ophthalmic artery may be visualized, thereby corroborating the experimental work of Elschnig and Walsh and King *in vivo*. In addition, this collateral circulation not only explains the failure of blindness to occur in the homolateral eye but the richness of this circulation may be adequate to fill the intracranial branches of the internal carotid artery and, therefore, may account for the paucity of neurological symptoms in some of these cases.

CASE REPORTS

Case 1. V.A. Hospital, #36805. V. B., a 50-year-old male, was admitted Mar. 31, 1953 with a chief complaint of "blackout spells." He had been in perfectly good health until 5 months previously when, on a Sunday afternoon drive, he suddenly noticed transient weakness of his right hand. Ten minutes later this happened again, and on the following day he had persistent weakness in that hand. There were no headaches, dizziness, or numbness in the hand associated with the weakness. There was no disturbance of speech. The patient was able to move his arm with normal strength but found that he was unable to extend his fingers in that hand. He had not returned to work since that time. On the day following his first episode, he was examined by his family doctor, who found his B.P. was 240 systolic. He was told that he had had a "shock" and was placed on a diet. He was advised to exercise his hand with a

small rubber ball. The weakness in his hand gradually subsided, and 1 month later he was feeling perfectly well and was able to go deer-hunting without difficulty.

Three and a half months before admission, the patient noticed his right arm had begun to shake and his legs felt weak. He was able to grab a bedpost with both hands but slipped to the floor and was unable to get up for 10 minutes. He was perfectly conscious but unable to talk during this period. The shaking in the right arm did not spread but gradually subsided. After this he was able to get up and talk without difficulty. He denied headache, nausea, vomiting, loss of weight, or other associated symptoms.

Examination. B.P. was 150/92, pulse rate 76, respiratory rate 20, and temperature was normal. He was a florid-faced, middle-aged male, who was a little given to "wisecracking." There was a slight left exophoria. The pupils were equal and reacted normally. Both disks showed blurring of superior margins with full veins but there were preserved physiological cups and no definite elevation of the disk margins. The visual fields were full. Vision was normal in each eye. Facial sensation was normal. There was a slight right facial weakness. Hearing was normal. The patient could name common articles readily. He was able to demonstrate the use of common objects but he had difficulty in performing motor acts on command, especially if they were at all complicated. For example, he was unable to do the heel-to-knee test until it had been done passively for him. He believed the present month to be March when in reality it was April. He had the day of the week correct, however. He demonstrated no spatial disorientation. The right hand was a little less strong than the left. Reciprocating movements on the right side were slower than on the left. Strength and tone in the legs were normal. Sensation was intact, including stereognosis and figure-writing on the fingers. The right arm reflexes were increased over the left.

Roentgenograms of the chest were normal except for multiple calcifications, possibly old histoplasmosis. Those of the skull showed very slight pineal displacement toward the left in the AP film. Hematological and urinary analyses were normal. NPN and fasting blood sugars were normal.

Arteriography. On Apr. 9, 1953 Dr. G. F. Hoessly performed percutaneous arteriography on the left side under pentothal anesthesia. The dye entered the external carotid artery despite numerous attempts to fill the internal carotid artery by replacing the needle lower and lower in the common carotid artery. The films revealed that in tracing the branches of the external carotid artery, an excellent demonstration of communication with the ophthalmic artery (Schurr[8]) was seen. The dye entered the intracranial portion of the internal carotid via the ophthalmic artery and, thereby, its branches were filled (Figs. 1 and 2).

Course. He suffered no untoward symptoms following the procedure. There was no change in his neurological findings or in the vision of the left eye, and he was discharged Apr. 22, 1953.

Final diagnosis was thrombosis of the internal carotid artery, left, secondary to arteriosclerosis.

Comment. This case of complete thrombosis of the internal carotid artery in its cervical portion demonstrates: (1) extraordinary lack of neurological signs and symptoms; (2) failure of blindness to occur in the homolateral eye; (3) that arteriography may reveal collateral circulation about a thrombosis of the internal carotid through the ophthalmic artery back into the intracranial portion of the internal carotid artery and its branches.

Case 2. V. A. Hospital #39099. C. O., a 61-year-old man, was admitted for the first time on Oct. 19, 1953. He was totally aphasic and the history was partially obtained by indirect methods. He was conscious and alert and able to shake his head "yes" or "no," but was totally unable to speak. He denied any pain prior to the present episode. He denied headache, dizziness, or visual symptoms. He was a chef at another hospital and had been hospitalized there for 6 weeks for right hemiplegia, which according to the patient had not improved. He had had no previous serious illness.

Examination. There was a Grade 3 to Grade 4 harsh aortic systolic murmur. The liver was enlarged one finger below the right costal margin; it was non-tender and had a sharp edge.

FIG. 1. *Case 1.* Lateral arteriogram. Left side injected in neck. External carotid filling only. External carotid (1) anastomoses with ophthalmic artery (2) and thence into the internal carotid (3). Note filling of anterior and middle cerebral vessels. (Retouched*)

FIG. 2. *Case 1.* AP arteriogram. Left side injected. Note filling of intracranial portion of internal carotid (1) which filled via the ophthalmic artery only, as seen in Fig. 1. (Retouched)

* The illustrations have been retouched for the sake of clarity of reproduction.

FIG. 3. *Case 2.* Lateral arteriogram. Left side injected. Nubbin of internal carotid (1) filled only. External carotid (2) anastomoses with ophthalmic artery (3) and thence into intracranial portion of internal carotid (4) which is very small and the dye stops there. (Retouched)

The pupils were round, regular, and equal and reacted to light and in accommodation. The fundi showed Grade 2 arteriosclerotic changes. There was a right facial weakness. The uvula deviated to the left. The gag reflex was present. Reflexes on the right side were exaggerated. There was a right Babinski. The right abdominal and cremasteric reflexes were absent.

The medical consultant felt that there was either rheumatic or congenital heart disease present with aortic stenosis. EKG was essentially within normal limits. The spinal fluid was normal. The patient had a very marked aphasia, more marked on the perceptive side. Sensory examination revealed a hyperaesthesia on the right side. The sensory changes suggested a mild thalamic syndrome.

The patient's condition remained essentially stable without evidence of improvement or of deterioration.

Arteriography was performed by Dr. John Carpenter, revealing that the internal carotid artery ended blindly several mm. above the bifurcation. A small amount of dye reached the circle of Willis via retrograde filling through the external carotid and ophthalmic artery and thence into the intracranial portion of the internal carotid, where it stopped. No filling of the internal carotid branches was seen (Fig. 3).

Course. The patient suffered no ill effects from the procedure and has remained aphasic and hemiplegic.

Comment. The arteriograms demonstrate the typical picture of the thrombosed internal carotid artery with just a nubbin of vessel patent. The external carotid anastomoses with the ophthalmic artery which can be traced to its origin from the internal carotid, and there the internal carotid is totally occluded.

SUMMARY

Two cases of spontaneous thrombosis of the internal carotid artery, proved by arteriography, are presented. The arteriographic appearance of collateral circulation from the homolateral external carotid artery to the ophthalmic artery is demonstrated. Blindness, diminution of vision and optic atrophy did not occur in either case. In one of these cases, with little neurological deficit, the branches of the internal carotid artery are shown to be filled by this route.

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THE EFFECT OF VENTRAL QUADRANT SECTION OF THE CERVICAL CORD ON HEMIBALLISMUS

M. Hunter Brown, M.D.,* and M. N. Walsh, M.D.†
Los Angeles, California

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Hemiballismus is a violent, uncontrollable movement of the arm and leg that is almost invariably unilateral. The origin of the term is somewhat obscure and was originally credited to Kussmaul by Oppenheim.[6] However, Moersch and Kernohan[5] were unable in their studies to verify this origin, and credit Jakob with this term suggesting the motion of tossing a ball by one side of the body.

Martin and Alcock,[2] as well as Moersch and others, have verified the usual pathology to be a lesion of the contralateral subthalamic nucleus (corpus Luysii). Most observers are now agreed that the illness, if truly ballistic in nature and not hemichorea, is usually fatal because of exhaustion with terminal cardiac failure or pneumonia within a period that varies from 1 to 6 weeks in most cases. The etiology has been vascular, usually hemorrhage or thrombosis, in the great majority of instances; however, occasional reports have appeared of subthalamic involvement by a neoplastic or granulomatous process. Meyers, Sweeney and Schwidde[4] believed that apparently bona fide cases of hemiballismus occur from involvement of the afferent or efferent pathways connecting to the corpus Luysii and possibly from pathology involving the corpus striatum and ventral neothalamus as well. The present evidence, however, is definitely clouded in attributing ballistic movement to locations in the basal ganglia and midbrain other than the subthalamic nucleus and its immediate projection pathways; certainly it appears that some case reports have confounded severe hemichorea with the pure ballistic movement. Meyers felt that there is some indication of somatotopic localization in the corpus Luysii with lesions rostrally causing movement of the head and neck, lesions of the middle portion affect-

* 1033 Gayley Avenue, Westwood Village, Los Angeles 24, California.
† 436 North Roxbury Drive, Beverly Hills, California.

ing the upper extremity, and of the caudal portion involving the lower extremity. Mettler and Carpenter[3] have been able to produce complex involuntary movements by stereotaxic lesions of the subthalamic nucleus in *Macacus rhesus;* subsequently they modified or eliminated these movements by fulguration of various extrapyramidal projections, including the lenticular fasciculus, the medial segment of the pallidum, and large lesions in the lateral thalamic nucleus.

Recent surgical efforts to ameliorate or abolish hemiballismus have all uniformly implicated partial or complete interruption of the pyramidal pathways. At the cortical level Bucy[1] extirpated areas 4 and 6, with a subsequent enduring left paralysis and apraxia. Meyers[4] has noted relief by linear subpial section between areas 4S and 6 anteriorly and 4, 3, 1, 2 posteriorly. Other interruptions, by Talairach, Paillas and David[8] at the capsular level and Walker[9] by cerebral pedunculotomy, have likewise shown considerable pyramidal deficit. We have been unable to find in the literature any cases of pure extrapyramidal interruption similar to that carried out by Putnam[7] in cases of chorea and athetosis until the present opportunity arose.

CASE REPORT

A 73-year-old white male was referred on March 3, 1953, for treatment of a violent hemiballismus of 5 days' duration. He was a known hypertensive of 12 years' standing and 6 years prior to admission he had had a minor cerebrovascular accident involving the right arm

FIG. 1. Recent fresh hemorrhage is noted in the right subthalamic nucleus. The old cystic lesion in the left basal ganglia with slight dilatation of the left lateral ventricle is apparent.

and leg, which completely cleared. Five days before admission he fell in his home, striking the occipital area; he was stunned and dazed but did not actually lose consciousness. The ballistic movements began immediately thereafter in the left arm, leg, and side of the neck. His family was not able to ascertain whether his stroke preceded the fall, or whether the reverse was the case. Within 24 hours the movements, at first gentle, became so violent that on several occasions he was thrown from his bed. They ceased completely with the sleep of exhaustion, but immediately returned with consciousness. For a few seconds at a time he was able to voluntarily control the movements, which then resumed with undiminished intensity.

Examination. The patient was conscious, cooperative, and somewhat restless. B.P. was 200/120, and pulse 86. The optic fundi showed grade II retinal sclerosis without hemorrhages, exudates, or choked disc. There was a severe hemiballistic movement involving the entire left side of the body, with very slight hypotonia and generalized reduction of reflex activity.

Hoffmann and Babinski signs were obtained in the right hand and foot respectively. Spinal fluid studies showed an initial pressure of 140 mm., 1 WBC, 3 RBC, positive Pandy test, total protein 78 mg. per cent, negative Kolmer, and colloidal gold curve 0235555320. Blood serology was negative. X-rays of the skull and chest were normal on admission.

Course. For several days the patient was treated by sedation, including large amounts of demerol, scopolamine, and barbiturates. The movements were controlled only when sedative drugs were sufficient in dosage to cause alteration of consciousness. Supportive therapy, including blood transfusions, oxygen, and parenteral fluids, was administered.

1st Operation. On the 5th hospital day, under pentothal supplemented by local anesthesia, two postparietal trephine openings were made, revealing no evidence of subdural hematoma on either side as an aftermath of his head injury. Ventriculography was carried out, which was negative for any space-occupying lesion. The left lateral ventricle was very slightly larger than the right; this was ascribed to mild cerebral atrophy secondary to his cerebral thrombosis 6 years previously.

Course. By March 14, 1953, the patient's condition had deteriorated further and it was obvious that the prognosis was hopeless without control of the involuntary movements.

2nd Operation. Under general anesthesia, a low suboccipital craniectomy and bilateral upper cervical laminectomy were performed with the patient in the upright position. When the dura mater was reflected the dentate ligaments were sectioned at the 2nd cervical level and the cord was rotated to the right. Incision for left ventrolateral tractotomy was made, beginning exactly at the point of attachment of the dentate ligament, extending 4.5 mm. in depth in a transverse direction, and emerging 2.0 mm. ventral to the left 2nd cervical motor root. The patient's blood pressure and respiration did not appear to change following the ventral quadrant section. He was returned to his room in fair condition.

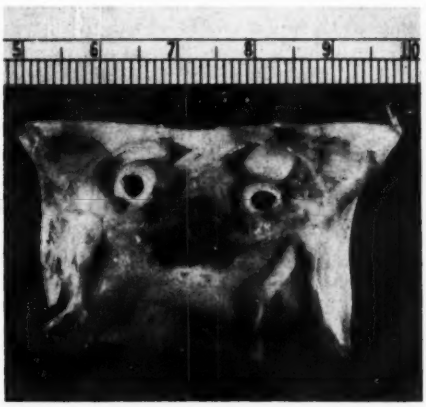

FIG. 2. Block removed from the basisphenoid. Gross sectional view shows pronounced atheromatous thickening of both internal carotid arteries.

Postoperative Course. The left arm and leg showed no evidence of any impairment of voluntary movement. The deep reflexes appeared to be slightly less active than prior to surgery, but were symmetrical on the two sides. There were no pathological reflexes elicited. There was a right hemianesthesia for pain and temperature below the level of the clavicle. No evidence of the previous ballistic movement could be observed, except for an occasional mild twitch of the head on the neck towards the left. Clinically this appeared to arise from the posterior rotator group of suboccipital muscles. During the subsequent week the patient remained slightly confused and gave evidence of increasing respiratory distress, despite vigorous chemotherapy, oxygen, and thorough bronchial aspirations. He expired on March 21, 1953, with clinical evidence of an extensive bilateral bronchopneumonia.

Necropsy. The calvarium was pierced by two recent postparietal trephine openings. The cortical surface of the brain showed prominent accentuation of the sulci with some bilateral involution present beneath the dura mater on both sides and slightly increased amounts of subdural fluid, but no evidence of subdural hemorrhage.

The brain was fixed and sectioned coronally. At the level of the mammillary bodies a circumscribed area of hemorrhage was noted in the right subthalamic nucleus, measuring 1.0 cm. in its anteroposterior dimension and up to 0.8 cm. in diameter (Fig. 1). A small old cystic

lesion, measuring 0.6 cm. in diameter, was observed in the left caudate nucleus. The vessels at the base of the brain showed diffuse prominent atheromatous plaque formations, but there was no evidence of old or recent occlusion (Fig. 2).

The spinal cord was grossly not remarkable, apart from a clean recent surgical laceration embracing the left ventral quadrant at the 2nd cervical level.

The pertinent visceral findings included multiple small pulmonary infarcts with an extensive confluent bronchopneumonia bilaterally and moderate pleural effusion on the left. There was advanced suppurative sinusitis with mucocele formation in the sphenoid and ethmoid cells, which presumably contributed to the pulmonary complications. The heart revealed a grade II coronary sclerosis with dilatation of the right auricle and ventricle, and there was chronic passive congestion of the liver, kidneys and spleen.

DISCUSSION

It is apparent that procrastination with medical measures and the faint hope of spontaneous disappearance of the movements is an unwise course in hemiballismus. A good deal of hesitation to embark on surgical interruption of the descending extrapyramidal projection pathways was because of the patient's age, poor general condition, and lack of any precedence in the neurosurgical literature for relief of the movements by the procedure carried out in this case. The long period of exhaustion and intermittent narcosis prior to surgical intervention diminished this patient's resistance to the point where he was finally unable to resist hypostatic pulmonary infection. Although hemiballismus is a rare disorder, it would appear that prompt diagnosis and operation will salvage some of these unfortunate patients in the future. In the future it would appear advisable to combine ipsilateral section of the upper 3 cervical motor roots with ventral quadrant section in order to control hemiballistic movements above the level of the surgical section.

CONCLUSIONS

1. A fatal case of hemiballismus has been described in which cessation of the movements was produced by ventral quadrant section of the upper cervical cord.

2. The importance of prompt diagnosis and surgical treatment in this uncommon but almost uniformly fatal disorder is emphasized.

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OCCIPITAL EPENDYMOMA WITH EXTRACRANIAL METASTASES*

LYMAN MAASS, M.D.

Department of Neurological Surgery, University of California School of Medicine, San Francisco, and the Neurological Section, Fort Miley Hospital, Veterans Administration, San Francisco, California

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Many reports of primary intracranial tumors with extracranial metastases away from the central nervous system have appeared in the literature. Meningeal sarcomas,[11] meningiomas,[22] pineal tumors,[20] hemangioblastomas,[1] melanomas,[9] and pituitary tumors,[10] all have been described as metastasizing tumors. There have been fewer cases of gliomas with metastases reported in the literature. Ependymomas with metastases, a case of which is presented below, are of even more infrequent occurrence.

CASE REPORT

1st Admission, Mar. 21, 1951. A 27-year-old white male entered the hospital complaining of progressive headaches and visual blurring which had been present for the preceding 8 months.

Neurological examination revealed a bilateral papilledema, right homonymous hemianopsia, and right facial weakness. Skull x-rays demonstrated a left occipital calcific mass. EEG revealed abnormal electrical activity in the left occipital area.

Ventriculography and a left parietal-occipital craniotomy were performed on Mar. 27, 1951. A 5 cm. globular tumor was encountered attached to the parasagittal dura mater and invading the left occipital cortex. Because of the dural attachment and the vascularity of the tumor, the surgeon thought it to be a meningioma.

Microscopic examination revealed extensive necrotic areas with surrounding banks of tumor tissue. The neoplasm was felt to be a glioma by all observers, and it was reported as an ependymoblastoma by the Armed Forces Institute of Pathology.

The patient was discharged 3 weeks after operation with residual pressure symptoms.

2nd Admission, Mar. 15, 1952. The patient had had signs of increased intracranial pressure and convulsions for the preceding month. Neurological findings were similar to those during his previous hospitalization. Lumbar pressure was 250 mm. of water with a protein of 140 mg. per cent.

On Mar. 20, 1952, the operative site was reopened; a large intracerebral cyst and several tumor fragments were removed.

The patient was discharged 2 months later after receiving 5265 r to the tumor area, given through three ports—left parieto-occipital, posterior occipital, and vertex. The therapy was administered over a period of 6 weeks in 100–300 r daily doses.

Microscopic examination of the second operative specimen revealed a typical ependymoma pattern.

3rd Admission, July 8, 1953. Six months previously hard masses had developed in the patient's neck (Fig. 1). He first noticed enlarged nodes in his left lateral cervical region, and later on the right side. For the preceding 2 months, symptoms of increased intracranial pressure had been present.

Examination revealed the scalp overlying the burr opening to be tense and enlarged, as if invaded by the tumor. A 4×6 cm. mass occupied the left lateral cervical area. On the right

* This report has been reviewed in the Veterans Administration and is published with the approval of the Chief Medical Director. The statements and conclusions published by the author are the result of his own study and do not necessarily reflect the opinion or policy of the Veterans Administration.

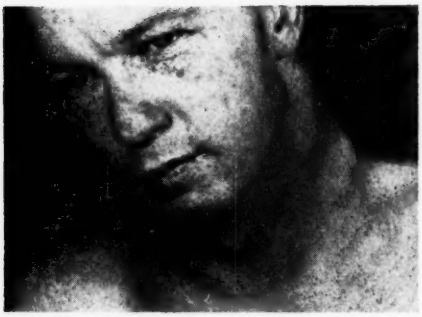

FIG. 1. Large cervical masses are demonstrated.

side a small 1×2 cm. node was palpable. Chest x-rays and standard laboratory tests were normal.

Removal of the right cervical node revealed tumor identical to the material obtained at the second operation. On July 16, 1953, a ventriculogram demonstrated ventricular displacement to the right. The left occipital horn was enlarged and practically reached the dura mater. Re-exploration of the operative area revealed considerable necrotic cortex extruding through the burr openings. A left occipital lobectomy was performed.

The patient improved temporarily, but progressively became more stuporous and died 2 months later on Sept. 28, 1953. Autopsy was refused.

Microscopic examination of the third operative specimen revealed necrotic and edematous tissue. No tumor tissue was seen.

Microscopic Examinations. The original tumor material demonstrates considerable calcification and necrosis. Figs. 2 and 3 show vascular attachments of elongated cells which are felt to be primitive ependymal cells. Figs. 4 and 5 are views of the same material in another

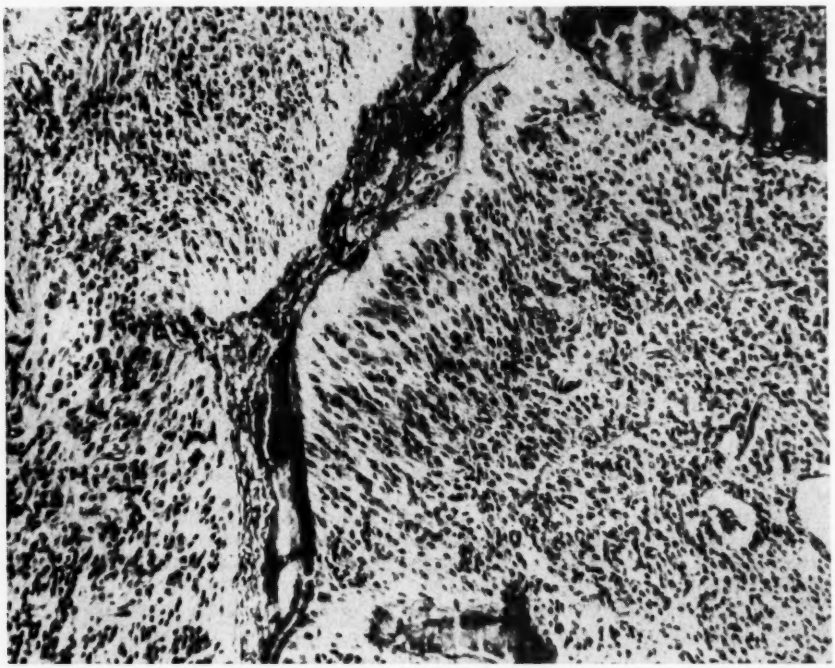

FIG. 2. Low power view of original neoplasm. Note attachment of cells to the blood vessel. Phosphotungstic acid hematoxylin (PTAH) stain, ×99.

FIG. 3. High power view of original neoplasm. Cells have large nuclei and short tail-like processes. They tend to align in a parallel fashion and attach to the blood vessel. These are early ependymal cells. PTAH stain, ×610.

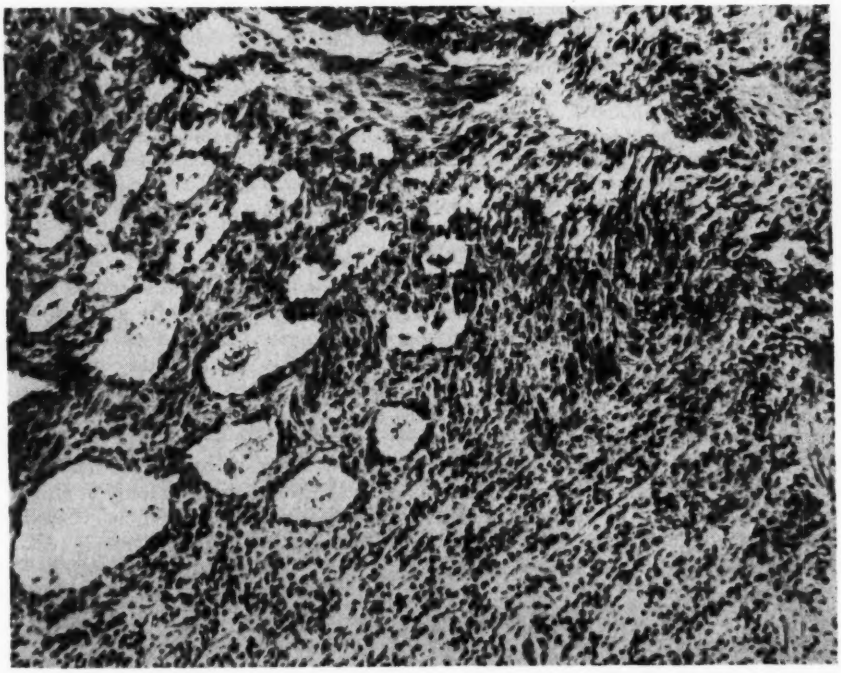

FIG. 4. Low power view of original specimen in another section. Note tendency to pseudorosette formation. Hematoxylin and eosin (H and E) stain, ×99.

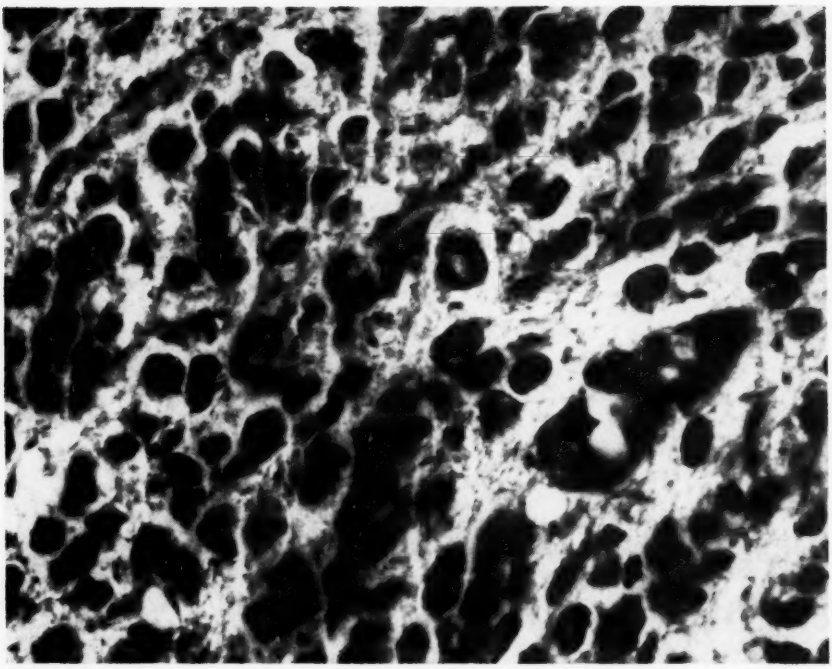

FIG. 5. Same section as in Fig. 4 under higher power. Note compressed pseudorosette formation. H and E stain, ×610.

field and suggest a tendency toward compressed pseudorosette formation.

The tumor tissue obtained from the second craniotomy has a more recognizable ependymoma pattern (Figs. 6 and 7). Pseudorosette formations are more ample and typical. Figs. 8 and 9 show sections of the lymph node biopsy. Under low power examination, the complete replacement of normal lymph-node architecture by tumor tissue can be observed. The capsule and subcapsular areas have been infiltrated by neoplastic tissue. Fig. 9 shows a cellular pattern very similar to that of the tumor obtained from the second operation (Fig. 7).

DISCUSSION

Winkelman and associates[22] recently reviewed the literature and found 48 cases of intracranial tumors with extracranial metastases, 10 of which were gliomas. We have found 3 additional cases, including our own described in this report. Winkelman *et al.*[22] classified all cases into one of three groups: (1) probably valid; (2) questionably valid; and (3) probably invalid. Their criteria are based upon documentation and description. We feel our case must be placed in the second group because of lack of a postmortem examination. In reviewing the cases reported in the literature, one is impressed with the number of medulloblastomas (Table 1). Three of the 4 cases reported were in adults. Medulloblastomas are not uncommonly confused with neuroblastomas or sarcomas. Pendergrass and Wilbur[17] reported their case in 1928 as a medulloblastoma, but upon review of the material in 1942[3] it was felt that the correct diagnosis was neuroblastoma.

TABLE 1

Summary of cases reported in the literature

Case	Author	Age Sex	Tumor	Location	Duration of Preoperative Symptoms	No. Ops.	X-ray Therapy	Post-op. Metastases	Postop. Survival	Location of Metastases
PROBABLY VALID CASES										
1	James & Pagel[12] 1951	25 F	Oligodendroglioma	Rt. parietal	3 yrs.	2	Yes	2 yrs.	4 yrs.	Nodules in scalp, cervical nodes, lt. lung, rt. femur
QUESTIONABLY VALID CASES										
2	Davis[7] 1928	31 F	Glioblastoma multiforme	Lt. temporoparietal	3 mos.	2	Yes	4 mos.	6 mos.	Subcutaneous masses, rt. arm, rt. scapula, lt. costal margin
3	Mittelbach[15] 1935	39 M	Glioblastoma multiforme	Lt. parietal	8 mos.	1	No	Found at autopsy	6 mos.	Lung metastases, hilar node invasion
4	Sachs *et al.*[18] 1936	38 M	Medulloblastoma	Rt. cerebellum	2 mos.	2	Yes	3 yrs.	5 yrs.	Subcutaneous mass over sternum. Cord implants
5	Nelson[16] 1936	24 M	Medulloblastoma	Rt. cerebellum	6 mos.	2	Yes	Found at autopsy	3 yrs.	Invasion 4 lower T vertebrae. Cord implants
6	Köhlmeier[13] 1941	38 M	Glioblastoma multiforme	Lt. parietal	1 yr.	3	Yes	3 mos.	4 mos.	Lung metastases. Tumor extension into neck. Cervical vein erosion
7	Šikl[19] 1950	52 M	Astroblastoma	Lt. frontoparietal	7 mos.	2	No	Found at autopsy	7 mos.	Metastases lung, T4 vertebra, ribs. Invasion bone flap, temporal muscle
8	Brandt[4] 1950	52 M	Glioblastoma multiforme	Lt. temporal	9 mos.	1	Yes	6 mos.	1 yr.	Metastases lung, lt. kidney. Tumor extension around ear and down neck
9	Cross & Cooper[8] 1952	20 M	Mixed type glioma	Lt. temporoparietal	2 mos.	1	No	3 mos.	9 mos.	Metastases lung apex, ant. abdominal subcutaneous area. Invasion scalp, temporal muscle, and around ear
10	Maass 1954	27 M	Ependymoma	Lt. occipital	8 mos.	3	Yes	6 mos.	3 mos.	Bilateral cervical node metastases
PROBABLY INVALID CASES										
11	Bailey & Bucy[2] 1929	43 M	Oligodendroglioma	Lt. parietal	17 yrs.	4	Yes	8 yrs.	8 yrs.	Tumor extension into neck
12	Wohwill[20] 1930	9 mos. F	Medulloblastoma	Vermis	—	-	Yes	6 mos.	—	Ganglioneuroma of rt. supraclavicular region
13	Pendergrass & Wilbur[17] 1928	32 F	Medulloblastoma	Rt. cerebellum	3 mos.	4	Yes	4 yrs.	4 yrs.	Multiple bony lesions by x-ray. Tumor later diagnosed neuroblastoma

In some of the reports shown in Table 1, it was stated that the intracranial tumor extended through the operative bony opening into the neck.[2,4,6,12,13] In 2 cases, invasion of the temporalis muscle was demonstrated.[6,19] Köhlmeier[13] found a cervical vein with intraluminal tumor extension from a glioblastoma multiforme extending into the neck. James and Pagel[12] demonstrated metastases to cervical node and scalp. In most of the cases, there were multiple operations and in 3 cases the bone

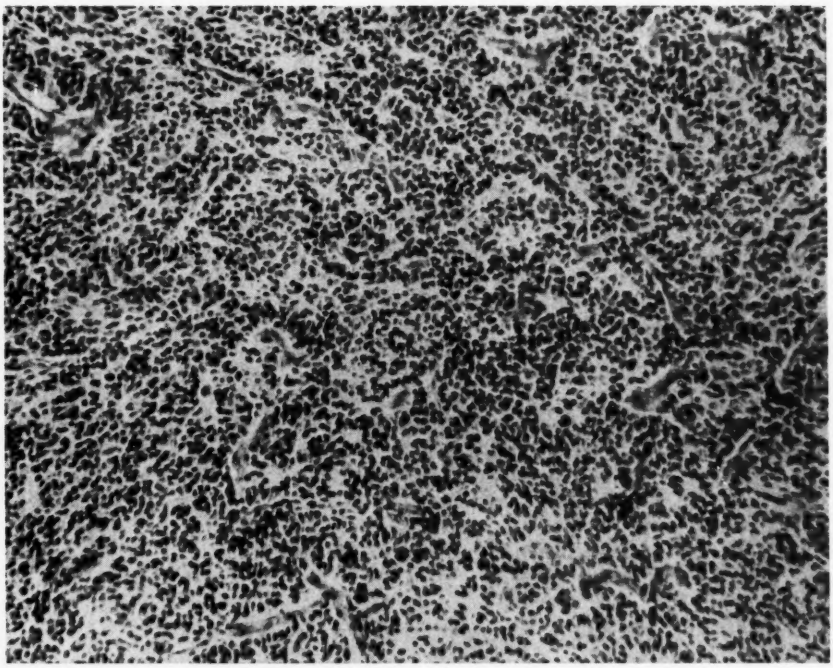

FIG. 6. Low power view of neoplastic tissue removed at second craniotomy. Note the more typical pseudorosette formation. H and E stain, ×99.

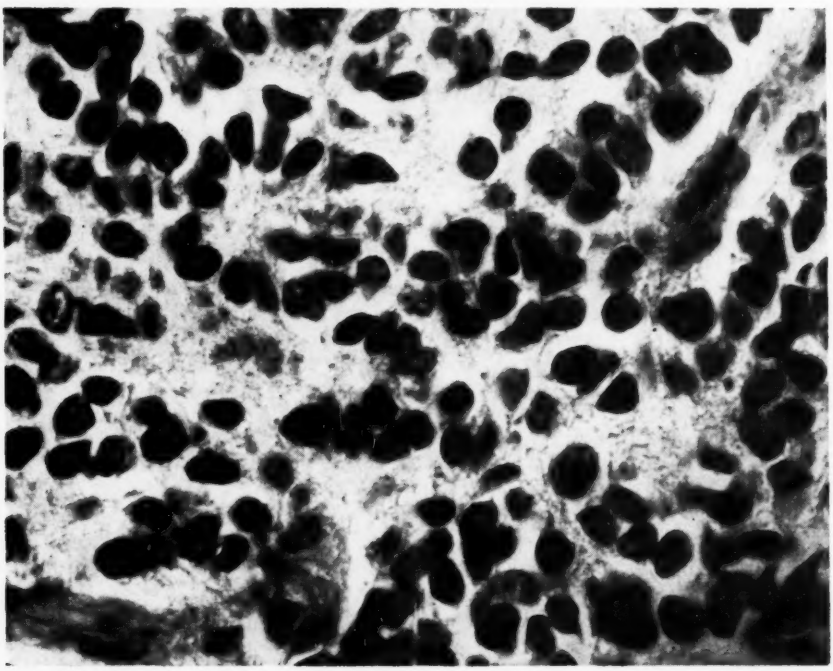

FIG. 7. High power view of same tissue as in Fig. 6. Note pseudorosettes. H and E stain, ×610.

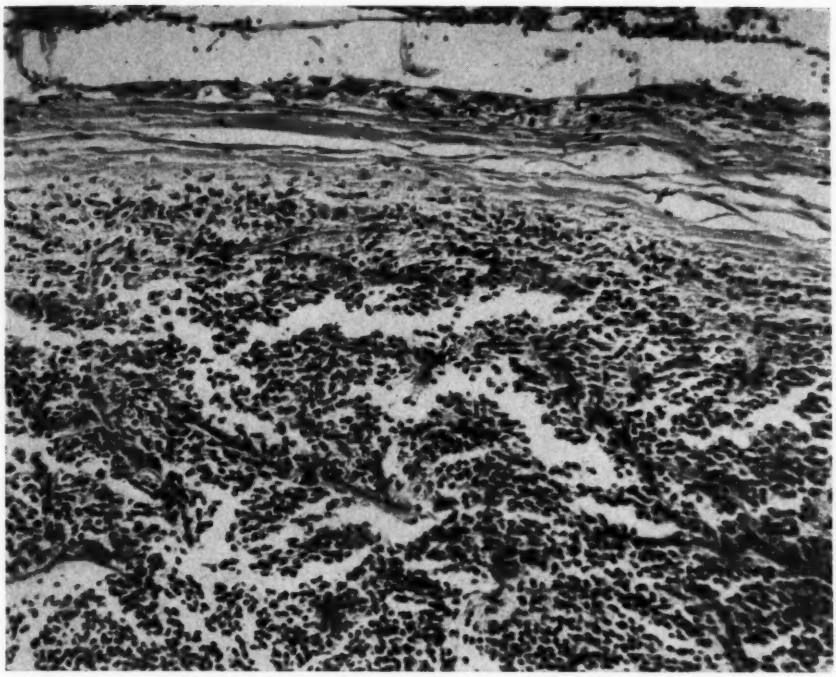

FIG. 8. Low power view of lymph node removed from neck. Note the complete replacement of lymph node architecture. There is tumor invasion of the capsule and subcapsular spaces. H and E stain, ×99.

flap was removed, providing ample opportunity for extracranial extension.

The higher incidence of non-gliomatous tumors associated with extracranial metastases is felt to be ascribable to hematogenous spread arising from invasion of the dural sinuses. Towne[21] reported a case of a meningioma that invaded the inferior longitudinal sinus and followed the venous pathway into the neck. Tumor tissue was removed from the internal jugular vein. Tompkins *et al.*[20] described a pineal tumor that invaded the straight venous sinus and gave rise to lung metastases. Gilmour[10] also reported an adenocarcinoma of the pituitary gland which invaded the cavernous sinus and gave origin to extracranial metastases.

Winkelman *et al.*[22] suggested that metastases from gliomas are infrequent because: (1) it is difficult for soft gliomatous tissue to penetrate the dural sinuses; (2) the cerebral veins that are thin-walled and held relatively loosely by the brain tend to collapse before allowing the entrance of tumor tissue; and (3) extracranial tissues are poor media for glioma growth.

MacCarty[14] quoted Penfield as stating, "metastases outside of the central nervous system are rare because of the astrocytic barrier around blood vessels. The same wall of astrocytic feet is thrown up against pia as well. But this latter barrier does not prove to be impassable."

Penfield[8] in 1937 stated that one element in the failure of metastases is the absence of lymphatic-vascular connections within the pachymeninges. Councilman[5]

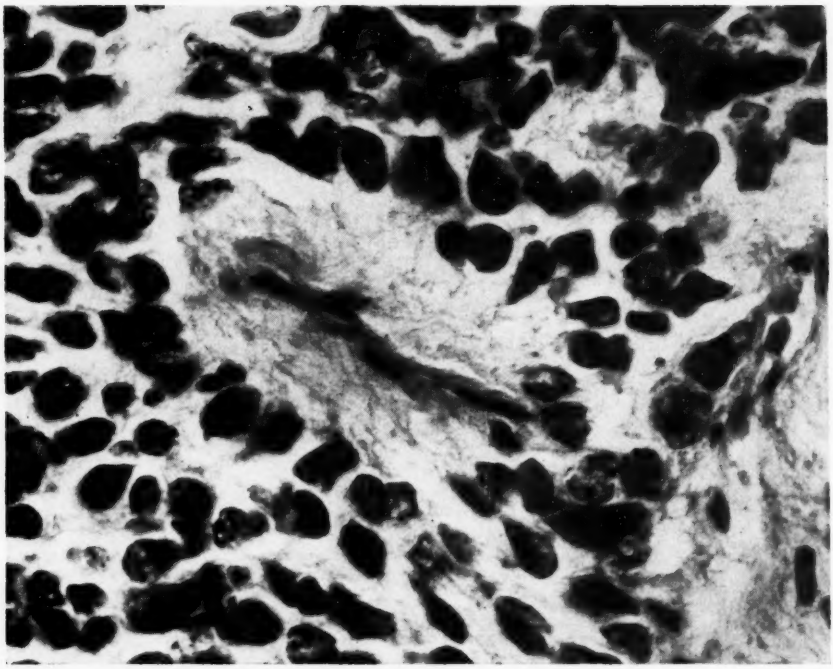

FIG. 9. Same tissue as in Fig. 8, showing formation of pseudorosettes in the lymph node. H and E stain, ×610.

felt that absence of lymphatics as well as a tendency for the tumor cells not to invade the blood vessels accounted for the lack of metastasis. MacCarty,[14] in studying metastasis of gliomas to the subarachnoid and ventricular spaces, concluded that the pia and subpial glia, ependyma and subependymal glia offered barriers to implantation in these spaces. Zimmerman and Maier,[24] who have produced experimental gliomas in mice, feel that there is no mesodermal resistance against metastatic gliomatous growth. They also postulate that failure of gliomas to invade vessels and the absence of lymphatic connections with intracranial structures account for the infrequency of metastases.

When extracranial metastases do arise from intracranial gliomas, there appear to be several possible routes. Invasion of the scalp or muscles attached to the skull will soon be manifested in the cervical lymph nodes. Direct tumor extension into the neck may also produce infiltration of nodes through lymphatic invasion or erosion into cervical veins. After implantation into the nodes, hematogenous seeding may occur. A third route of metastasis may be produced by the rare occurrence of gliomas arising from cell rests (heterotopic glial nests) in the dura mater, leptomeninges, or in mesodermal tissue outside the central nervous system. Dural tumors, as proved by their reported frequency (14 cases in Winkelman's series), are more prone to extracranial metastases. There is also the possibility that introduction of a tumor embolus into a dural sinus or cerebral vein during an operation could produce metastases.

SUMMARY

1. A case report of an occipital ependymoma with evidence of cervical metastases has been presented.

2. The literature concerning extracranial metastases from intracranial gliomas has been reviewed.

3. Theories explaining the rare occurrence of extracranial metastases from intracranial gliomas have been discussed and possible routes of metastases have been suggested.

The author would like to express his appreciation to Dr. Nathan Malamud for his assistance in reviewing the microscopic examination of the material in this case.

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EXCISION OF MULTISACCULAR SUPRATENTORIAL ANEURYSM OF INFRATENTORIAL ORIGIN

CASE REPORT

ELDRIDGE CAMPBELL, M.D., DOGAN PERESE, M.D., AND NOLTON H. BIGELOW, M.D.
Departments of Surgery and Pathology, Albany Medical College, Albany, New York

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Multisaccular aneurysms arising from the circle of Willis represent relatively uncommon lesions about which little has been written. In the following case a large multisaccular aneurysm was successfully resected despite the fact that the sac, while located above the tentorium, actually took origin from the basilar tree. This experience indicates that the large size of such a lesion need not necessarily preclude its satisfactory removal.

CASE REPORT

A.H. #68228. J. F., a 33-year-old housewife, entered the Albany Hospital Feb. 22, 1953, because of convulsive seizures.

Past History. Fifteen years previously she had suddenly and without warning lost consciousness and fallen to the ground. On awakening she experienced severe generalized headache. When first seen in 1940 she had suffered three such attacks. At that time no aura nor actual convulsion had been observed but the headaches had been so severe as to require morphia. On one occasion nausea and projectile vomiting had persisted for 24 hours. Stiffness of the neck was not recalled.

No neurological abnormalities were found at that time, save that the right optic disk appeared suspiciously blurred. The visual fields were normal on perimetric examination. Lumbar puncture revealed clear, xanthochromic CSF under a pressure of 180 mm. of water. The fluid contained 56 red blood corpuscles and 34 lymphocytes; protein content was 65 mg. per cent; sugar and chlorides were within normal limits; and Wassermann reaction was negative. Roentgenograms of the skull and an encephalogram were normal. Although a diagnosis of aneurysm of the circle of Willis was made, no surgical therapy was undertaken.

Readmission in 1953. She reported that the "spells" had become more frequent and had not been controlled by any of a variety of anticonvulsive medications. They sometimes occurred daily for about a week, or weekly, or again might skip several weeks. She believed them particularly likely to appear just before menstruation or when she was very tired. There was sometimes an aura of a "tight feeling in my forehead," of "gas cramps in my stomach" or of "tension all over." This was soon followed by staring and abrupt suspension of any activity. On some occasions she lost consciousness but no convulsive movements were ever observed. Headaches in the frontal and occipital regions sometimes followed these attacks but occasionally occurred independently.

Between the two hospital admissions she had married and borne three normal children.

Examination revealed an intelligent young woman, rather apprehensive and just recovering from a severe headache. The skull was externally negative and no bruit could be heard. No neurological abnormalities were detected save for mild fanning of the toes under scopolamine. Perimetry disclosed left upper quadrant homonymous hemianopsia. Roentgenograms of the skull (Fig. 1) now revealed a considerable amount of speckled calcification scattered over a wide area in the region of the right temporal and occipital lobes. There was a single ring-shaped zone of calcification near the cortex. EEG disclosed slow waves emanating from the right temporoparietal region.

The diagnosis of aneurysm was again made, and because of the hemianopsia and roentgenological changes, it was believed to lie in the right temporal lobe. A right carotid angiogram (Fig. 2) showed distinct upward displacement of the middle cerebral group with elevation of the supraclinoid portion of the internal clinoid. A vessel which originated from the

FIG. 1. Roentgenogram showing finely speckled calcification in the right temporal lobe region.

internal carotid artery proximal to the middle cerebral, believed to be the posterior cerebral artery, was displaced upward parallel to the latter. No vessels were seen entering the large temporal area in which calcification was seen. Hence the diagnosis was changed from "aneurysm" to "tumor."

Operation (March 3, 1953). Under sodium pentothal, nitrous oxide and oxygen a right temporo-occipital bone flap was turned. The tissues were not abnormally vascular. The dura mater was quite tense but became slack after the left ventricle was tapped through a left frontal trephine opening. The surface of the posterior portion of the temporal lobe was pale

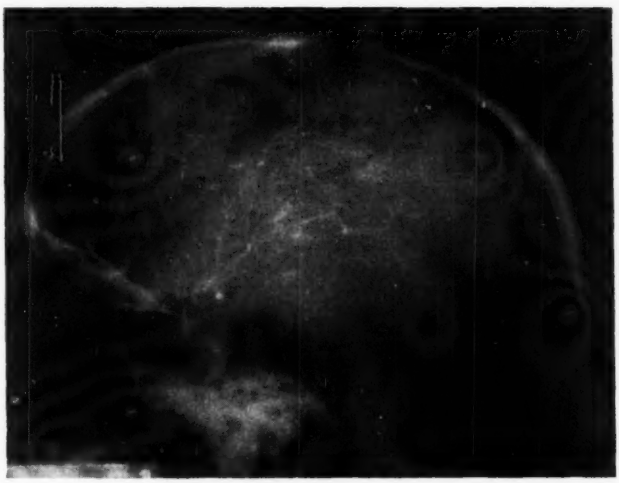

FIG. 2. Right carotid angiogram showing upward displacement of middle cerebral and posterior cerebral (?) arteries.

and the gyri were flattened by an underlying mass. The cortical veins were not engorged and did not appear to contain arterial blood. After division of the veins of L'Abbé, upward retraction of the temporal lobe revealed a potato-like mass, ca. 7 cm. in diameter, lying upon the tentorium. Its lateral portion felt solid and was not pulsating, but the medial pole, which extended to within 2 cm. of the midline, was pulsating, and at its inferior pole a distinct thrill could be felt. There were three small sacculations on the main aneurysm (Fig. 3). After resection of the overlying portion of the temporal and occipital lobes one could discern two large vessels (ca. 3–5 mm. in diameter) entering the medial pole of the aneurysm via the incisura. No emissary veins were observed then nor subsequently. The posterior cerebral tree appeared to be independent of the aneurysm.

With the finger as a guide it was then possible to encircle the neck of the aneurysm at the incisura with a large aneurysm needle carrying a strand of medium silk. By means of the latter a broad piece of hernia tape was then circumducted. This was then tied tightly about the neck, causing the pulsations to disappear. However when resection of the aneurysm was begun forceful arterial bleeding ensued. This was readily controlled when the tip of the finger compressed the incoming vessels against the incisura. The hernia-tape ligature was then gently compressed with a Kelly clamp, and all bleeding ceased immediately. The aneurysm was then excised, leaving a neck about 1 cm. in diameter protruding beyond the clamped tape. This was closed with a lock stitch of 5-0 arterial silk. The hernia-tape ligature was further reinforced with a heavy silk tie. No further bleeding ensued when the clamp was removed.

FIG. 3. Large aneurysm clearly showing two secondary or daughter aneurysms. Between these two structures there is a third pyramidal projection, which may represent the early developmental stage of another outgrowth.

The patient's condition had not altered and there was no visible change in the circulation of the remaining portion of the occipital lobe. It was thus presumed that this aneurysm arose from some portion of the basilar arterial tree other than the posterior cerebral.

Pathologic Report. The formalin-fixed specimen received in the laboratory consisted of an aneurysm measuring 4.5×3×3 cm. This roughly ovoid structure was composed of a relatively thin grey-white membrane in which foci of calcification, evident atherosclerosis, were present. Projecting outward from the primary sac were two secondary or daughter aneurysms, which measured 2×1×1 cm. and 1.5×1×1 cm. respectively. There was also a roughly pyramidal protuberance consisting of a wide-based but pointed tip, measuring 1.5×1×1 cm., which appeared to represent the early development of a third daughter aneurysm. The lumen of the aneurysmal sac contained not only freshly congealed (and formalin-fixed) blood, but also laminated ante mortem thrombus, later confirmed by histologic examination.

Course. Convalescence was complicated by a small extradural clot and beta hemolytic Staphylococcus aureus infection. The bone flap was sacrificed and terramycin, to which the organism was sensitive, was administered in doses of 500 mg. every 4 hours by mouth. The temperature, which had reached 104°F. on the 4th day after operation, soon returned to normal, and the wound healed slowly. However her general condition remained excellent. There was never any evidence of subdural infection.

At the time of discharge, 12 days after operation, the left plantar response was extensor in type, and ankle clonus was present on the left. Left homonymous hemianopsia was present; however macular vision appeared to have been spared and visual acuity was 20/20 in each eye. At the present time (12 months later) the visual field defects remain but the pyramidal tract signs have almost completely disappeared. She looks well, has no complaints and is carrying out her household duties normally, Dilantin gr. 1½ is being administered twice

daily; she has had no further seizures nor headaches. Cranioplasty will be performed at a later date.

COMMENT

It is regrettable that vertebral angiography was not performed preoperatively, for the origin of the aneurysm might then have been precisely disclosed. It is unlikely, however, that the operative attack would have differed.

Rupture of the neck of an aneurysm is an ever-present hazard in its removal. This experience suggests the possibility of the protection of this friable structure with hernia tape before it is clamped, clipped or tied. In any case, the induction of local hypotension by noose[4] or acupressure is distinctly advantageous. Actual closure of the aperture by fine arterial suture is often feasible, as has previously been demonstrated in the case of certain berry aneurysms of the middle cerebral[4] and anterior communicating arteries.

It has long been known that aneurysms of the circle of Willis vary greatly in size, situation and number; relatively less attention has been given to their variability in shape. A few scattered reports describe aneurysms which were "dumbbell-shaped," "multilobular," or with "daughter" sacs arising from the parent aneurysm (Table 1). From the standpoint of diagnosis a mural thrombus may interfere with the arteriographic demonstration of a sacculation or, on the contrary, may give the erroneous impression of a lobulation, when none actually exists.

The usual stereotyped description of berry or saccular aneurysms represents them as having an ovoid or spherical appearance. Consequently the incidence of lobulated aneurysmal structures is greater than is realized. A review of the 52 autopsy specimens of "berry" or "congenital" type aneurysms of the circle of Willis preserved in our Department of Pathology reveals 4 instances of sacculation (Table 1) while Wolfe[26] refers to 2 such cases in a series numbering 47.

The available descriptions of the gross appearance, location and size of many of the previously recorded examples of this condition are summarized in Table 1. Löfstedt[15] noted a dumbbell-shaped aneurysm by angiography. This lesion may truly have been lobulated, but the possibility of artefact caused by thrombus has to be considered. Otherwise, except for the present case, all other instances of lobulated aneurysms as given in Table 1 represent postmortem studies.

More than half of the above-described aneurysms had ruptured. From the descriptions available it appears likely that many of these lesions might, with presently available methods, have been successfully resected.

SUMMARY

1. Successful extirpation of a large multisaccular aneurysm is recorded. While it lay upon the tentorium, it originated from vessels which came up through the incisura.

2. The possibility of protecting the neck of certain aneurysms with hernia tape before occlusion is suggested. Local hypotension induced by noose or, as in this instance, by acupressure, affords greater safety. If desirable, the neck may be clipped, tied, or in certain instances, closed by suture.

3. A compilation of reported instances of multisaccular aneurysms is given. It is believed that such structures occur more frequently than has heretofore been realized.

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TABLE 1

Multisaccular aneurysms

No.	Author Year	Age	Sex	Rupture	Site of Aneurysm	Remarks
1.	Serres[23] 1826	59	F	?	Ant. comm. art.	Biloculate, size of musket ball
2.	Lebert[14] 1836	68	M	—	Basilar	Size of hen's egg with 3 outpouchings
3.	Smith[24] 1842	54	M	—	Branch of basilar	Size of small apple, multilocular
4.	Ogle[18] 1865	46	F	−	Lt. ant. cerebellar	Nodulated, size of walnut
5.	Ogle[18] 1865	53	F	+	Lt. mid. cerebral	Size of walnut, divided into 2 lobules
6.	Bristowe[3] 1867–68	27	F	+	Lt. mid. cerebral	¾″ in size with 2 projections large as cherry stones
7.	Lorber[16] 1868	49	M	+	Rt. ant. cerebral	Size of pigeon egg with projection large as hazelnut
8.	Church[5] 1869	13	M	+	Rt. mid. cerebral	Bilocular, form and size of walnut; rupture of larger sac
9.	Engle[9] 1876	17	F	+	Basilar	Double sac; anterior sac plum size, posterior sac size of hazelnut
10.	King[12] 1876	30	M	+	Rt. ant. cerebral	Biloculate
11.	Bramwell[2] 1887	43	F	−	Rt. post. cerebral	Huge, 2×1¾×1½″, with secondary sac
12.	Bramwell[2] 1887	31	M	−	Rt. int. carotid	Greatest diameter 3″, with 2 small subsidiary sacs
13.	Hutchinson[11] 1889	26	M	?	Basilar	Lobulated, 2×1 cm. Aortic valvulitis with vegetations, so may be mycotic
14.	Pitt[21] 1890	16	F	−	Rt. mid. cerebral	Bilobed; considered mycotic because of bacterial endocarditis
15.	Kümmell[13] 1911	37	M	?	—	Plum-sized; in 2 parts
16.	Drennan[7] 1921	44	M	+	Ant. comm.	Lobulated, 3 mm. in diameter
17.	Duguid[8] 1925	17	M	+	Junct. lt. vert. at basilar	Trilobed. 2nd sac arose from 1st, and 3rd sac arose from 2nd
18.	Parker[19] 1926	20	M	+	Lt. post. comm. at mid. cerebral	Dumbbell-shaped; 2nd unruptured aneurysm; coarctation of aorta
19.	Székely[25] 1928	31	M	+	Ant. comm.	Lentil-size with pea-size protuberance
20.	O'Crowley & Martland[17] 1939	42	M	+	Rt. mid. cerebral	Lobulated; 2 unruptured aneurysms lt. mid. cerebral; polycystic kidneys
21.	Evans & Courville[10] 1939	—	—	?	Lt. mid. cerebral	Double swelling seen in photographs; 2 other aneurysms
22.	Richardson & Hyland[22] 1941	49	M	−	Rt. vertebral	Dumbbell-shaped, nodular 5×3×2 cm. in size

TABLE 1 (*Continued*)

No.	Author Year	Age	Sex	Rupture	Site of Aneurysm	Remarks
23.	Dandy[6] 1944	45	F	−	Rt. ant. cerebral	3.2 cm. in length, hour-glass shape
24.	Bassett[1] 1949	31	M	+	Rt. ant. cerebral	Doubly lobulated; vascular anomaly also present
25.	Löfstedt[15] 1950	−	−	?	Ant. cerebral	Double sac (dumbbell) seen by angiography only
26.	Authors' case	−	F	+	Lt. mid. cerebral	1.0×0.5×0.5 cm., biloculate
27.	Authors' case	39	F	+	Lt. int. carotid at mid. cerebral	1.5×0.7×0.4 cm., small nodule on sac
28.	Authors' case	54	F	+	Lt. int. carotid at mid. & ant. cerebral	2.3×0.8×0.6 cm.,biloculate
29.	Authors' case	38	F	−	Rt. mid. cerebral	1.5×0.7×0.7 cm. with nodule 0.3 cm. on sac. Ruptured symmetrical aneurysm of lt. mid. cerebral
30.	Present case	33	F	+	Basilar tree	4.5×3×3 cm. Two daughter sacs and 1 incipient daughter sac

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BILATERAL ANGIOMA OF CHOROID PLEXUS

CASE REPORT*

T. H. McGuire, M.D., James Greenwood, Jr., M.D., and Berne L. Newton, M.D.
Department of Surgery and Pathology, Methodist Hospital and Baylor University College of Medicine, Houston, Texas

(Received for publication May 7, 1954)

A review of the literature disclosed 8 reported cases of angioma of the choroid plexus, but no instance of bilateral angioma was recorded.[1–7,9] Liber and Lisa[8] reviewed the symptomatology of 6 cases. All patients except 1 were under 17 years of age and 3 were infants. All but 1 had evidence of cerebrospinal hemorrhage. Hydrocephalus was evident in the 3 infants, as it was in our case. Our case presents essentially the picture of infant hydrocephalus with intraventricular hemorrhage which has been relieved by bilateral excision of angiomas of the choroid plexus.

CASE REPORT

W.T., a 3-month-old white male infant, was admitted to the neurosurgical service at the Methodist Hospital on Jan. 9, 1952, because of excessive increase in the size of his head. The birth weight was 7½ lbs. and the immediate post partum period was uneventful. At a routine 6-weeks' examination, the parents were told that his head was larger than normal, and 4 weeks later the head showed a progressive enlargement, for which the child was hospitalized.

Examination. The circumference of the head was 44 cm. and the fontanelles were open and bulging. There was a rough, raised hemangioma, 2.5 cm. in diameter, on the extensor surface of the right arm at the elbow (Fig. 1). There was marked anemia, the RBC being 2,240,000, hb. 6.1 gm., and WBC 10,800 with a normal differential. Bleeding and clotting time were normal.

Bilateral subdural taps were negative, but at a depth of 2½ cm. xanthochromic, blood-tinged fluid was recovered from the ventricle. PSP dye injected was recovered almost immediately in the spinal subarachnoid space. Ventricular fluid contained 141 mg. per cent protein, 1,750 RBC, and 24 lymphocytes. Ventriculography showed symmetrical dilatation of the entire ventricular system.

Course. The child received multiple small blood transfusions and ventricular taps were done daily with the removal of 30 to 50 cc. of CSF. By the 12th day the fluid was free of gross

* Presented at the meeting of the Southern Neurosurgical Society, Houston, Texas, March 13, 1953.

blood, but the xanthochromia persisted. After 6 weeks the fluid was clear, colorless, and contained only 3.8 mg. of protein, with no cells. The fontanelle, however, continued to be tense when taps were temporarily discontinued.

Operations. Seven weeks after admission, a right choroid plexectomy revealed a discolored, red-purple plexus about twice the normal size.

Seven days later, a left choroid plexectomy (Fig. 2) disclosed a similar plexus of deep red color, about three times the usual size.

Course. Following surgery the child retained its feedings normally and the fontanelle remained depressed. One week later the hemangioma of the right elbow was removed and 4 days after this the child was discharged from the hospital. Circumference of the head was 43.5 cm. and his weight 16 lbs.

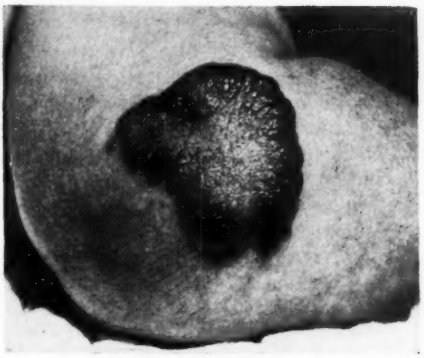

FIG. 1. Hemangioma of the skin of the right arm.

Pathological Report (Methodist Hospital #19605, right, and #19708, left). The plexuses were essentially similar. They were enlarged, dark red, and glistening. The normal papillary projections seemed ironed out. The plexus on the left side was larger, measuring $1.5 \times 1.4 \times 0.5$ cm.; the right was $1.8 \times 0.8 \times 0.5$ cm.

Microscopically the striking feature was the presence of ramifying blood-filled channels lined by endothelial cells and with scant and, for the most part, compressed stroma composed of spindle-shaped cells and collagen. Few recognizable papillary processes were seen, and little evidence of remaining lining epithelium was present. Through the sections a well-marked vasodilatation was seen which appeared distinctly apart from the angiomatous pattern noted above.

Examination of sections from the skin lesion on the arm revealed the characteristic pattern of a hemangioma, predominantly of capillary type.

Subsequent Course. One year after discharge from the hospital, the child weighed 28 lbs. and the head measured 50.5 cm. The fontanelle was closed. He was talking in monosyllables, was able to say some short phrases, and sat alone. He could walk about the room by holding on to furniture. Subsequent development has been normal and the fontanelle remains closed.

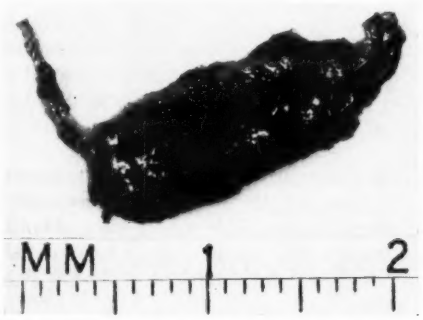

FIG. 2. The gross appearance of the choroid plexus removed from the left lateral ventricle.

COMMENT

Of 25 children who have had plexectomies since 1939, 3 can be classified as excellent results with regard to normal physical and mental development with control of hydrocephalus. Microscopic review of the lesions in these 3 cases showed that 1 should have been classified as angioma and another as having at least marked vasodilatation suggesting angioma. The third plexus was not remarkable. The production of excessive fluid as a cause of hydrocephalus in some cases is at least a rational speculation.

SUMMARY AND CONCLUSIONS

A case is reported of a 3-month-old infant with hemangioma of the skin of the right elbow, communicating hydrocephalus, and bilateral angioma of the choroid plexus. Following choroid plexectomies, the hydrocephalus has been arrested for a period of 2 years.

The role of angioma of the choroid plexus in production of hydrocephalus must be considered from the standpoint of overproduction of fluid as well as from intraventricular hemorrhage, since, in this case at least, there was no relief in intracranial pressure after there was clearing of the ventricular fluid.

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A NEUROSURGICAL INSTRUMENT TABLE

Lyle A. French, M.D., and Genevieve Scholtis, R.N.*
Division of Neurosurgery, Department of Surgery, University of Minnesota, Minneapolis, Minnesota

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This is a report on a neurosurgical operating room table† that has been used at the University Hospital, Minneapolis, for the past three years and is considered a definite adjunct to both the nurse and the surgeon. This table has made it possible to obtain satisfactory assistance from graduate nurses who have had little operating room experience and from student nurses.

With the use of this table the nurse can easily anticipate the needs of the surgeon since she has complete view of the operative field. All the instruments necessary for any type of operative procedure can be placed on the table within view of both the nurse and the surgeon. The table itself is stabile, will not tip and can be elevated or lowered to accommodate any desired position in which the patient is placed. The platform is adjustable to the height of the nurse.

From the standpoint of the anesthetist, it is advantageous for it permits excellent

* Operating room supervisor, University Hospital, University of Minnesota.

† Manufactured by Phelan Manufacturing Company, 2826 Cedar Avenue, Minneapolis, Minnesota.

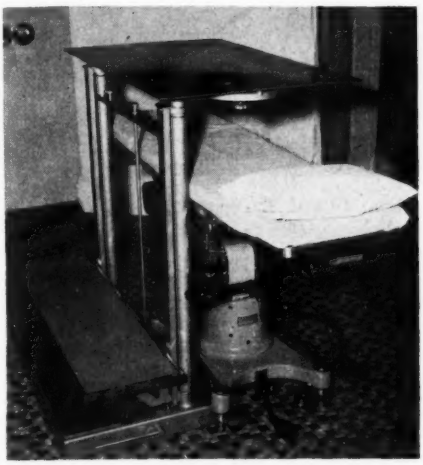

FIG. 1. Photograph of instrument table in position against operating table. The various levers used to adjust the height of the table and foot platform can be seen.

observation of and access to the patient. Administration of intravenous fluids, adjustments of airway, and introduction of a spinal needle are facilitated. When used with patients under local anesthesia it produces a better psychological effect for it removes for the patient the sensation of being covered up.

The table has been used in performing laminectomies and sympathectomies, as well as craniotomies.

FIG 2. Photograph showing table in use. Ready access to the patient is the chief advantage for the anesthesiologist.

NOTICES

AMERICAN BOARD OF NEUROLOGICAL SURGERY

Examinations were given by the American Board of Neurological Surgery in Chicago, Illinois, May 1–4, 1954, and the following were certified:

BAKAY, LOUIS Massachusetts General Hospital, Boston 14, Mass.
BLAKE, Paul S. 1050 Medical Arts Bldg., Minneapolis 2, Minn.
BRACKETT, CHARLES E. University of Kansas Medical Center, Kansas City, Kan.
DAWSON, RALPH E. 1021 Mott Bldg., Flint, Mich.
DUNBAR, HOWARD S. 430 East 63rd St., New York 21, N. Y.
FOUNTAIN, EDMUND M. Hermann Professional Bldg., Houston, Texas
GRIZZARD, VERNON T. 512 Greenleaf Bldg., Jacksonville 2, Fla.
HAZOURI, LOUIS A. 1528 13th Ave., Columbus, Ga.
HETHERINGTON, JOHN 822 Hume Mansur Bldg., Indianapolis, Ind.
JOHNSON, A. BEAUMONT, II Kennedy Hospital, Memphis 15, Tenn.
KITE, William C., JR. 47 South Lake Ave., Albany, N. Y.
KVERNLAND, BRUCE 833 S. W. 11th Ave., Portland, Ore.
MCFADDEN, JOSEPH T. 405 Wainwright Bldg., Norfolk 10, Va.
MCLAURIN, ROBERT Cincinnati General Hospital, Cincinnati 29, Ohio
NASH, TOM Medical Arts Bldg., Dallas, Texas
PETERSON, ERIC W. Ottawa General Hospital, Ottawa, Ont., Can.
PICAZA, JORGE A. Calle 15, No. 759 Vedado, Havana, Cuba
RUGE, DANIEL 700 North Michigan Ave., Chicago 11, Ill.
SACHS, ERNEST, JR. Hitchcock Clinic, Hanover, N. H.
SMILEY, GORDON 319 First Savings & Loan Bldg., Saginaw, Mich.
SPEAKMAN, THOMAS J. 841 Teglar Bldg., Edmonton, Alta., Can.
STERN, WALTER E. Dept. of Surgery, Medical Center, University of California at Los Angeles, Los Angeles, Calif.
WARREN, WILLIAM S. 458 Government St., Mobile, Ala.
WEN, HSIANG LAI (Foreign) Muntok Bangka, Indonesia
WEYAND, ROBERT D. 411 30th St., Oakland, Calif.

AMERICAN NEUROLOGICAL ASSOCIATION

At the 79th annual meeting of the American Neurological Association held in Atlantic City, New Jersey from June 14–16, 1954, the following officers were elected for the year 1954–1955: President, Dr. Percival Bailey; President-Elect, Dr. J. M. Nielsen; First Vice-President, Dr. A. R. Vonderahe; Second Vice-President, Dr. Paul C. Bucy; Secretary-Treasurer, Dr. H. Houston Merritt; Assistant Secretary, Dr. Charles Rupp.

LATIN-AMERICAN NEUROSURGICAL CONGRESS

The 6th Latin-American Neurosurgical Congress will be held in Montevideo, Uruguay from March 21–25, 1955. An interesting program has been prepared, the main subjects being brain herniations, pain surgery and dyskinesias. There will also be a symposium on the thalamus. It is hoped that many from the United States will attend. Papers should be sent to the General Secretariat of the Congress—Convención 1287, Montevideo, Uruguay before March 1, 1955 if they are to be published in the transactions of the Congress. Abstracts of papers should be sent not later than January 1, 1955.

PSEUDOTUMOR CEREBRI

GEORGE D. ZUIDEMA, M.D., AND SOLOMON J. COHEN, M.D.
Department of Surgery, Massachusetts General Hospital, Boston, Massachusetts, and Department of Pediatrics, Babies Hospital, the Presbyterian Hospital of the City of New York

(Received for publication May 7, 1954)

INCREASED intracranial pressure is a condition that can be produced by any of several mechanisms. The more common of these are: obstruction to the normal circulation of cerebrospinal fluid; space-occupying intracranial lesions; cerebral edema; hypertensive crises; and the general group of conditions that produce local or generalized elevation of the venous pressure, such as dural sinus thrombosis or right ventricular failure.

In most cases the etiology of the intracranial hypertension is readily determined. However, in a certain group of patients who present the signs and symptoms characteristic of elevated intracranial pressure, the usual diagnostic studies such as ventriculography or arteriography fail to reveal any abnormality. This group is characterized clinically by: 1) increased intracranial pressure; 2) normal ventricular system; and 3) normal cerebrospinal fluid, except for pressure. The syndrome is known variously as pseudotumor cerebri, intracranial hypertension of unknown etiology, serous meningitis or otitic hydrocephalus.

We felt that by long-term follow-up studies of this group some subtle, originally present but unrecognized changes, might become apparent, and thus help to explain a bizarre clinical picture. For this purpose it was decided to study once again the 22 patients reported by Dr. Dandy[1] in 1937 from this hospital; and in addition to follow 39 similar patients seen here from 1937 to the present, in an effort to discover if time had made any pathological basis clear, and to determine, if possible, what clinical course and prognosis might be expected in cases of this kind.

REVIEW OF LITERATURE

Many authors have attempted to clarify the etiology of this condition.[4] In 1936 Davidoff and Dyke[2] described similar cases under the name of serous meningitis. Yaskin, Groff, and Shenkin[11] have more recently reported 12 additional cases.

In 1937 Dandy[1] reported 22 cases of pseudotumor cerebri from the Johns Hopkins Hospital. He noted that the pressure was often subject to rapid and extensive changes, remaining elevated for varying periods. He postulated that such fluctuations were caused by temporary variations in vascular permeability, and therefore associated with transient cerebral edema.

Five cases were reported by Sahs and Hyndman[9] in 1939. They reasoned that cerebral edema of a type characterized by rapid development and slow resolution offered the most satisfactory explanation. They emphasized the

absence of an inflammatory process, as evidenced by the normal cellular pattern of the cerebrospinal fluid.

Of considerable interest is the case reported by McCullagh,[7] in which a similar picture seems to have been secondary to menstrual edema. A low-sodium diet and extract of pregnant urine controlled the condition without recourse to subtemporal decompression.

Elkins and Rack[3] reported 3 additional cases. They emphasized that this diagnosis cannot be allowed to rest on inadequate or incomplete diagnostic studies; and that even in the absence of a definite diagnosis, advancing papilledema with decreasing visual acuity and intractable headache may require surgical decompression as an emergency procedure.

Symonds[10] in 1931 first called attention to the syndrome in which infection of the ear is followed by intracranial hypertension; and Gardner[5] in 1939 reported 10 additional cases. In the latter series the presence of dural sinus thrombosis was proven at autopsy or mastoidectomy in 5 cases, and suggested by a positive Tobey-Ayer test in 3 other cases. In 1 patient the process subsided spontaneously, while in the remaining 9 repeated lumbar punctures were required. In addition, subtemporal decompression was used in 4 cases. Gardner said,

"If, as is not infrequently the case, one of the lateral sinuses constitutes the chief emissary for the intracranial circulation, then I believe it is possible for a thrombosis of this sinus alone to produce the picture of increased intracranial pressure. . . . I am inclined to attribute the increased intracranial pressure simply to engorgement of the intracranial veins, plus, in some cases, sterile subdural effusion resulting from external pachymeningitis. Recovery from this state of increased intracranial pressure occurs when, by means of recanalization or the development of collateral supply, the return of venous blood from the cranial cavity is once more adequate."

Ray and his co-workers[8] have, in the course of their development of dural sinus venography as a diagnostic tool, demonstrated the occurrence of dural sinus thrombosis in 2 of the 9 cases published in their report in which the clinical picture was identical with that of pseudotumor cerebri. One of these patients had otitis media and mastoiditis, but the other had no such history or physical findings.

It seems likely that the syndrome of pseudotumor cerebri actually is caused by a number of different pathological entities. As we learn more about the physiology of the cerebrospinal fluid circulation we can expect to separate certain patients with demonstrable causes of intracranial hypertension from those who must remain classified as idiopathic cases. Such has happened to those patients with adhesive arachnoiditis who originally must have fallen into this group.

CASE MATERIAL

The aim of this study was twofold: 1) to determine if long-term follow-up review of cases might contribute to the discovery of a more clear pathological basis; and 2) to discover the clinical course and prognosis of the syndrome.

To achieve this end, 2 groups of cases were selected, and follow-up reports were obtained by means of questionnaires which were submitted to both the patient and his family physician. The forms consisted of the following questions:

1. What has been your general health since your operation at Johns Hopkins Hospital?
2. Has there been any recurrence of the symptoms which brought you to Johns Hopkins Hospital?
3. Have you developed any other serious illnesses since your last visit to Johns Hopkins Hospital?
4. Have you had:
   a. severe headaches
   b. recurrent nausea or vomiting
   c. failing vision
   d. nervous system troubles
   e. convulsions or fainting spells
5. When was your last visit to your family physician?
6. Did your operation at Johns Hopkins Hospital benefit your condition?
7. Have you had to return to any hospital for the trouble for which you came to Johns Hopkins Hospital?
   If so, when and where?
8. What is the address of your family physician?
9. Can you add any further information which you think might help physicians in treating other patients with your trouble?

Group 1. Dr. Walter Dandy[1] in 1937 reported a series of 22 patients with the pseudotumor cerebri syndrome. We sent the questionnaire to these 22 patients, their families, or their physicians, and were successful in obtaining follow-up reports on 12 of the original 22. The remaining 10 questionnaires were returned because the patient or physician had moved, or the address given in the hospital record was inadequate. There is good reason, however, to believe that these 12 patients are representative of the group as a whole and significant.

Ten of the 12 patients followed are living and well today. Nine of the 12 had had subtemporal decompressions. There were 2 deaths in this group: (1) Fifteen years after her original subtemporal decompression, V.R. (Case 2, U-27949) was found to have an intracranial aneurysm. She was explored, but died of surgical complications. (2) Eight years following operation, B.P. (Case 5, U-37125) manifested what was diagnosed elsewhere as multiple sclerosis. No postmortem examination was obtained, however.

In regard to the 10 patients with this syndrome who did well, it is difficult to relate their improvement to any specific therapy. Dandy's original suggestion of a temporary change in vascular permeability associated with transient cerebral edema remains a good explanation (Table 1).

Group 2. The patients in this group are those who were seen in the Johns Hopkins Hospital from 1937 to 1953. A survey of neurosurgical and neuromedical admissions during this period yielded a total of 58 cases fulfilling the criteria of: 1) increased intracranial pressure, 2) normal ventricular system, and 3) normal cerebrospinal fluid, except for pressure. Of these 58 pa-

TABLE 1

Follow-up times on the 10 surviving patients of Dandy's original 22

Time	Number of Patients
5–10 years	3
10–15 years	3
15–20 years	3
over 20 years	1
	10

tients, some later showed demonstrable cause of intracranial hypertension leaving 39 with classical pseudotumor syndrome (Table 2).

The 6 cases in which an association with upper respiratory infection was noted appear to be quite typical of those described by Symonds[10] and Gardner,[5] and designated otitic hydrocephalus.

Of the 4 cases later proven to result from actual brain tumor, in none was the correct diagnosis made on the first admission, and in the fourth case the tumor was not detected until the third admission, and this in spite of normal ventricular pattern. Three tumors were astrocytomas, and one was a melanosarcoma, apparently primary in the meninges.

It is important to note that the diagnosis was made at various intervals after the onset of symptoms, the times ranging from 3 to 9 months. This has important bearing prognostically, for it suggests that if an actual tumor is present, one may fairly expect it to become manifest within a year at most after the onset of symptoms. It also suggests, although our data are admittedly limited, that if a patient survives without recurrence or progression for 2 years, his prognosis improves markedly.

It is noteworthy that the syndrome of pseudotumor cerebri is seen most often before the age of 30 years. Of the 39 cases followed since 1937, 44 per cent were in the 20–30 year age group; and 41 per cent of Dandy's cases were in the same age group (Table 3).

The sex incidence is also significant, for both series show a marked preponderance of pseudotumor syndrome in females. Of Dandy's 22 patients,

TABLE 2

58 cases of intracranial hypertension from 1937 to 1953

Number of Cases	Explanation of Intracranial Hypertension
6	Associated with respiratory infections or otitis media.
5	Dural sinus thrombosis, proven at autopsy or operation.
3	Postoperative deaths, without autopsy examination.
4	Brain tumor found on subsequent admission.
1	Rheumatic heart disease with mitral stenosis.
39	Pseudotumor cerebri; no demonstrable cause found.
58	

TABLE 3

Distribution of cases in regard to age groups

Age Group	Dandy's Series	J.H.H. Series, 1937 to 1953
0–10	1	5
11–20	2	8
21–30	9	17
31–40	4	6
41–50	6	1
51–60	0	2
	22	39

16 were females, a 3.7 to 1 incidence; and 29 of the 39 patients in the more recent series were likewise females. This is nearly a 3:1 incidence. In a number of patients the severe headaches occurred in association with menses, and in one instance the onset of symptoms coincided specifically with the onset of a menstrual period. In only one case did the syndrome develop during pregnancy.

From the questionnaires submitted to the second group of patients it was found that the results in general agree very closely with those of the first group.

Of the 39 cases reviewed we were able to follow 26. Five patients had died, with 21 patients surviving (Table 4).

TABLE 4

Follow-up times on 21 cases studied from 1937 to 1953

Time	Number of patients surviving
0–5 years	11
6–10 years	4
11–15 years	6
	21

These 21 survivors represent a survival rate of 87 per cent, a rate identical with that found in Dandy's group. The causes of death and duration of survival are shown in Table 5. It is noteworthy that in only 3 of the 26 cases could death be attributed to a neuropathological condition.

Of the 21 survivors, only 9 had a recurrence of symptoms at a later date. These symptoms ranged from headaches and blurred vision to a complete recurrence of the original syndrome. The type of treatment used in these cases is shown in Table 6. Since subtemporal decompression was offered only to the more severely ill patients, it would seem that the prognosis is good even in this group.

One patient (J.H.H. 106203) had a craniotomy elsewhere when her symptoms persisted. Thrombosis of the cerebral veins was found. She has done well for 15 years postoperatively.

TABLE 5

Survival times and causes of death in the cases from 1937 to 1953

Case	Time of Survival	Cause of Death
1	12 months	"Probable organic brain disease" (only report available).
1	14 months	"Progressive CNS disease" (only report available).
1	11 years	Myocardial infarction.
1	13 years	Pneumonia and "heart disease."
1	?	Cause of death unknown. No autopsy.
5		

In addition we followed 4 of 6 patients in whom the pseudotumor syndrome appeared after an upper respiratory infection. These cases were classified as otitic hydrocephalus (Table 2). Three have done well, while one patient continues to have headaches and blurred vision.

DISCUSSION

A summary of our experience with the pseudotumor syndrome is given in Table 7.

In recent years rapid strides have been made in the development of new diagnostic techniques, and in the improvement and refinement of older methods. Despite these advances some intracranial lesions continue to defy diagnosis by the methods currently at hand. Present procedures for the demonstration and diagnosis of intracranial vascular abnormalities consist of two general types. Intracranial angiography by injection of contrast media into the carotid or vertebral arteries provides good visualization of the arterial system but venous visualization is likely to be inadequate and limited to the delayed "flush" phase of venous filling. Ray *et al.*[8] have developed the technique of dural sinus venography as a diagnostic tool in the evaluation of intracranial disease. Their method employs: 1) direct injection into the superior sagittal sinus of a contrast agent through a catheter introduced into the sinus; 2) retrograde injection of a contrast agent through a catheter introduced into the basilic vein of the arm and passed upward into the internal jugular vein to the superior bulb. Their published series of 9 cases so studied includes 2 cases in which dural sinus thrombosis was conclusively demon-

TABLE 6

Types of treatment used and long-term results

Number of Cases	Treatment Used	Results
2	Repeated lumbar punctures	Excellent
8	No treatment	Excellent
11	Subtemporal decompression	Excellent in 6, good in 5

TABLE 7

Summary of cases

Period	Number of Patients	Number Followed	Number Alive
1930–1937	22	12	10
1937–1953	39	26	21
	61	38	31

strated. It is of interest that one of these patients had otitis media and mastoiditis. The other patient (their Case 6) treated by removal of the thrombus remained well for 5 months postoperatively, thus far reported.

It appears therefore that dural sinus venography promises to be an additional diagnostic tool capable of yielding valuable information in patients with intracranial disease.

Again it must be emphasized that the diagnosis of pseudotumor cerebri is one that should be made only after exhaustive studies.

Patients presenting with this syndrome can be classified into three major groups: (1) Those with actual brain tumor, but in whom the disorder is not manifest enough for ready diagnosis. Conscientious follow-up of these cases will yield the correct diagnosis in a short time because of their progressive nature and the eventual development of localizing neurological signs. (2) Those with dural sinus thrombosis, usually associated with an upper respiratory infection, in whom the disease disappears probably as recanalization occurs. (3) The remaining patients tentatively regarded as having "idiopathic" pseudotumor cerebri, pending further study. This group has, on follow-up, been shown to have a relatively good long-term prognosis.

A striking point which emerges from such a study is the similarity between the cases of dural sinus thrombosis, whether or not it is preceded by a respiratory or middle ear infection, and the cases of pseudotumor cerebri. We feel, as others have, that it is likely that many, or perhaps even most, of the cases now designated as pseudotumor cerebri are in reality caused by unrecognized dural sinus thrombosis. It is possible that wider use of such diagnostic methods as dural sinus venography will confirm this impression.

TREATMENT

A variety of methods have been employed in the treatment of idiopathic intracranial hypertension. In milder cases repeated lumbar punctures as indicated by the clinical state of the patient are sufficient. In the more pronounced cases subtemporal decompression is indicated; and operative removal of a dural sinus thrombus has been reported by Ray.[8]

Gardner[5] states, "The chief value of subtemporal decompression in these cases is not that it causes a satisfactory reduction of the intracranial pressure but that the degree of tension in the hernia serves as a guide as to when a therapeutic lumbar puncture should be done."

Actually, subtemporal decompression serves as more than simply as indicator for therapeutic lumbar punctures. Admittedly, its decompressive value is somewhat overestimated; nevertheless, it may in itself at times be the means of preserving vision in the face of advancing papilledema. Its advantage lies in the fact that it is a method for achieving a steady type of decompression as opposed to the intermittent type of decompression obtained by repeated lumbar punctures alone. It may also be the instrument for providing subjective relief, because splitting the dura mater relieves the tension on a structure, the stretching of which is believed to be responsible for the severe headaches commonly present.

It seems that subtemporal decompression has an important place in the treatment of the severely ill patient with intense headaches and progressive loss of visual acuity. The picture of impending visual loss described by Holmes,[6] in the absence of primary eye disease, includes any one of the following clinical signs: (1) Rapidly developing papilledema. (2) High-grade papilledema (over 5 diopters) with retinal hemorrhages and exudates. (3) Marked retinal arteriolar constriction. (4) Narrowing of the visual fields. (5) Brief periodic blackouts, even if papilledema is not severe.

Other indications include extreme degrees of intracranial hypertension, and the general clinical state of the patient. Under these conditions subtemporal decompression must be considered without delay, even when the diagnosis of pseudotumor cerebri has been established by a normal ventriculogram.

SUMMARY

A study of the clinical syndrome of: 1) increased intracranial pressure, 2) normal ventricular system, and 3) normal cerebrospinal fluid, except for pressure, is presented. This syndrome seems to be caused by a number of different pathological entities. The role of dural sinus thrombosis in its pathogenesis is discussed, and is felt to be significant even in cases not preceded by a recognized infectious process.

At follow-up of 22 cases described by Dandy in 1937, a total of 12 were available for study. Of these, 10 patients were found to be living and well. Two had died, one of surgical complications following an intracranial aneurysm, and one probably of multiple sclerosis. This experience suggests a rather good long-term prognosis.

Fifty-eight additional cases studied in the Johns Hopkins Hospital since 1937 are reported. Of these, 11 were probably cases of dural sinus thrombosis; 4 patients proved to have actual brain tumor; 3 died after exploratory craniotomy at which no pathology was found, and no autopsy was obtained; 1 case was complicated by rheumatic heart disease with mitral stenosis. The remaining 39 cases of pseudotumor cerebri are analyzed. The sex incidence shows a predominance of females in a ratio of 3:1. The highest age incidence was found to fall in the 20–30 year group. Similar findings resulted from an analysis of Dandy's 22 cases.

Different methods of therapy are discussed, and the indications for subtemporal decompression in this condition are presented.

It is emphasized that the diagnosis of pseudotumor cerebri should be one of exclusion, to be made only after exhaustive diagnostic procedures have been carried out. An argument is presented for further use of venography in the diagnosis of intracranial lesions.

We would like to thank Dr. David B. Clark of the Department of Medicine of the Johns Hopkins Hospital for advice and encouragement in the preparation of this study.

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PERCUTANEOUS VERTEBRAL ANGIOGRAPHY

PIERRE NAMIN, M.D.

Neurosurgical Clinic, La Pitié, Paris, France*

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THE purpose of this study is to describe the modifications of form and situation of the blood vessels produced by neoplasms situated in the territory of the vertebral artery, with some remarks about thrombosis. Reference will be made only to gross anatomy of radiological significance, by means of brief examples chosen from the 162 vertebral angiographies performed in the neurosurgical clinic of the Pitié between 1948 and July, 1953. The principal characteristics of the normal and pathological angiogram will be set forth, with insistence on the harmlessness and relative simplicity of the method and description of a personal technique.

HISTORY

Vertebral angiography began in 1933 when Egas Moniz[3] succeeded by exposing the artery in the subclavicular region, temporarily ligating the peripheral end and making a retrograde injection. Many scattered attempts followed; many methods were proposed and were soon abandoned. It was only in 1947 that three independent schools developed valid techniques and soon three series of results were available. In 1949, Sugar, Holden and Powell[9] published a series of 20 angiograms obtained by transcutaneous puncture in the vertebral canal by an anterior approach. In 1950, Lindgren[2] published a series of 60 obtained by a similar method. Radner used an entirely different method. He introduced a catheter into the radial artery and guided it into the vertebral. In 1951,[7] he published the results of his method in 221 cases with a remarkably large percentage of successes. Finally, in 1952, Sergent *et al.*[8] published a study of a series of 130 vertebral angiograms obtained by the technique described below.

TECHNIQUE

We utilize a needle similar to a lumbar puncture needle, 7 cm. long, 0.8–1 mm. in diameter, with an obturator. The bevel should be as short as possible. The adjustment of the syringe to the needle is made directly without the interposition of any adaptor. The syringe is a simple glass syringe of 10 cc. capacity, of which the advantage is its lightness. The contrast medium employed is diodone, a soluble salt of iodine in feeble concentration (40.5 or 45 per cent). The quantity of the mixture in each injection does not exceed 6–7 cc. We make rarely more than three injections. In the interval of the injections we do not use citrated solution by the drop method. We are content to put the obturator in the needle, after having placed it in the citrated solution with which we rinse the syringe.

* Chief: Professor D. Petit-Dutaillis.

We use general anesthesia only in infants and in some pusillanimous or agitated subjects. In the same way, we reduce the local anesthesia to the minimum, using only a few drops of novocain in contact with the artery. As a matter of fact, we prefer to give the patient some medication, usually phanergan rather than derivatives of morphine, of which the depressor effect is known, preceded or not by an enema of 4 gm. of chloral.

We have used two methods for puncturing the artery; we may approach it from the anterolateral region of the neck or at the base of the cranium. In the anterolateral region of the neck, the artery is in the transverse canal and must be punctured between two transverse processes, generally between C5 and C6, or C4 and C5. The artery is here accompanied by the vein which is lateral to it, and a cervical root which crosses its posterior face. The patient is lying on his back with the head in moderate hyperextension. With the left index finger one depresses the tissues of the neck just below the great horn of the hyoid bone, in contact with the lateral border of the thyroid cartilage, or better, the cricoid thyroid space, so as to push the package of nervous and vascular tissue laterally. The needle is thrust into the depression thus created and comes to strike against the transverse process. One inclines it then upward to engage it in the intertransverse space in the direction of the superior transverse aperture.

Usually, as soon as the obturator is withdrawn, a flow of blood shows that one is in the lumen of the artery. Sometimes it is necessary to displace the needle slightly—to slightly withdraw it a little—for it is rather frequent that one has penetrated entirely through the artery. Sometimes a pain shoots into the shoulder showing that one has touched the cervical root. One must withdraw the needle a bit for it is too deep. Sometimes darker blood flows slowly in a regular flood showing that one has punctured the vein. The needle is then too far lateral and it must be replaced more medially.

Ordinarily it is easy to puncture the artery in the transverse canal; it is easily found and usually well fixed. On the contrary, it is rather frequent that the injection is made in part, or wholly, in the sheath of the artery, for it is rather difficult to maintain the needle well placed. In this case there is provoked a spasm of the artery, without any clinical signs, which permits one to obtain only poor images of difficult interpretation. The reason is that the direction of the needle tends to be perpendicular to that of the artery. Even on giving the needle a direction as oblique as possible it is difficult to catheterize the artery sufficiently. Also the needle traverses the subhyoid muscles which contract considerably during movements of swallowing. The needle is then subject to important displacement which can alter the position of the point. Because of the frequency of this accident, we have searched for another method that avoids this difficulty.

When the vertebral artery has left the transverse passage in the atlas, it changes its course and is directed a little bit backward, especially medially, to come into contact with the superior face of the posterior arch of the atlas where its passage marks its course by a little excavation, sometimes transformed into a tunnel visible in a lateral radiogram. The artery in this passage turns about the lateral mass of the atlas to which it is adjacent. It then perforates solid fibrous planes between laterally the capsule of the occipital atlantoid articulation, and medially the posterior occipital atlantoid membrane. The artery at this level is not accompanied by its vein; it is not yet formed. The first cervical nerve is not of importance. There is here, therefore, a segment of the artery that is easily catheterizable because of its direction.

It is covered by muscles that are very little movable, in a region where the sensitivity is particularly obtuse. Therefore it is believed that once the needle is introduced into the lumen of the artery it penetrates for several millimeters and maintains itself fixed. Although this puncture, like any manual maneuver, requires a little practice it is, after all, rather easily successful.

The patient is placed usually flat on his abdomen with his forehead on the table. The needle is plunged in a transverse plane, in a little depression between the sternocleidomastoid and the trapezius, just posterior to the point of the mastoid process. At a depth of about 2 cm., the needle comes into contact with the lateral masses. Bony contact is fundamental. One must find it before going ahead with the puncture. Moreover it is usually easily found. Then one directs the point of the needle a little bit posteriorly and below and one searches the contact with the posterior arch of the atlas, of which one follows the superior face about 2 or 3 mm. Then one withdraws the obturator and, generally, arterial blood flows out. If one does not succeed it is well to make a radiogram centered on the atlas, leaving the needle in place by which one will see the situation of the point of the needle in relation to the vascular notch of the atlas. It is then easy to correct its direction.

With this method we have had the most regular successes, never a spasm of the artery. For a long time we used this method only in those cases in which we had failed with the usual anterolateral method. One must remark, however, about the possibility of puncture of the cisterna magna, which will be demonstrated by a flow of spinal fluid. This happened to us twice. This accident makes one stop the operation, but it is without any gravity and can be avoided. For this purpose one must (1) always search for the bony contact of the lateral masses, which is the best protection, (2) never seek to overcome the fibrous resistance of the occipital atlantoid membranes, and (3) never make an injection when there is any doubt. As a matter of fact, it is easy to puncture the artery and it is still easier to keep the needle in place because there is no risk of secondary displacement at the time of the injection. We have no experience of what might happen if the injection were made into the cisterna magna, and do not wish to have. We believe that that could only be the result of a gross error and not apt to happen to a surgeon.

RADIOLOGICAL TECHNIQUE

We utilize an apparatus of 4 kenotrons. With a rotating anticathode it makes several exposures with one single activation. We usually used these constants: 200 ma., 80 kv., 0.2–0.3 sec. exposure. We use a plate changer of very elementary principle, regulated by the hand. It enables one to take easily 6 pictures in 4 seconds. Usually we are content with 3 pictures for each direction just about 1 sec. apart. The first gives an image of the arterial phase; the second of the arteriolar phase, and the third of the venous phase. As a matter of fact, there is usually some difference in the timing of the venous phase, the superficial veins being filled sooner than the deep veins in the system of Galen.

In order to protect the operator, we use a diaphragm, a localizer and a lead screen which is interposed in front of the head of the patient and the hand of the surgeon because naturally it is not possible to use gloves which contain lead.

We take two or three series of plates successively. The first one is lateral and cen-

tered a little posterior to the sella turcica. The second is anteroposterior in the sagittal plane, with an obliquity of about 30 degrees, the rays entering 3 or 4 cm. in front of the coronal suture and leaving at the external occipital tuberosity, that is, in the frontosuboccipital plane of Worms and Bretton (if the patient is lying on his abdomen, this will be a suboccipital frontal, with the same angle). The third is in the plane of Hirtz, the head being strongly retracted, the rays entering submentally and leaving at the apex. This view seems to us much less useful than the preceding one, for it is used only in special cases.

ANATOMICAL STUDIES

Reading the plates obtained may be the source of numerous difficulties, because of the superpositions and extraordinary tortuosity of the vessels. Classical dissection is not easy because of the overlapping and deep vessels. For this reason we have applied to the study of the vertebral system a method utilized for other organs, particularly the liver, in the laboratory of Doctor Delmas, Professor of Anatomy, Faculty of Medicine, in Paris.

A plastic material is used, soluble in acetone, easily colorable, injected into the vessels of a brain freshly removed, after washing out the vessels previously. This material solidifies in contact with the trace of water which is in the vessels. One has only to destroy all organic substance by prolonged immersion in a strong acid for several days to make a perfect mould of the arterial and arteriolar systems.

We thus treated 20 human brains and the study of these 20 moulds, thanks to the irreplaceable three dimensions, led us to a clearer understanding of the somewhat mysterious revelations of the X-ray plates. The venous system, unfortunately, does not lend itself to this sort of study, not only because the sinuses are frequently embedded in bone, but especially because a recurrent injection could not remount the course of the normal physiological circulation and would lose itself in the carotid territory. From the study of our moulds and of our numerous plates, we have come to a certain number of conclusions, some personal and others confirming previous works by the Portuguese, Swedish and American schools. We shall describe them as they were seen on the radiological plates.

THE ARTERIOGRAM

The lateral plates show a projection in the sagittal plane of the basilar trunk and of the vertebral injected, of which it is the continuation. This vascular trunk, from the posterior arch of the atlas to its termination, describes consistently a triple curve like a cupid's bow. The first curve is concave posteriorly; the second is concave anteriorly; the third is concave posteriorly. The principal trunk remains at a slight distance from the clivus. The preprotuberal cistern is in front of it. We insist on these two signs: the triple curvature and the interclivoarterial space, the importance of which will be shown in the discussion of tumors of the cerebellum.

The principal vascular trunk is at a rather variable angle with the plane of Frankfort. The angle has an average of 73 degrees; it varies from 50 to

80 degrees. It never terminates below the clinoidal line (a line parallel to the Frankfort plane but passing through the anterior clinoid process). It can be as much as 2 cm. above the Frankfort plane but generally is about 0.6 cm. The distance from the point of termination of the basilar trunk to the prolongation of the quadrilateral plate varies between 1.2 cm. and 1.5 cm. depending upon whether the trunk penetrates more or less into the interpeduncular cistern. On the average it is 0.6 cm.

The inferior cerebellar arteries are most variable; they seem to be always present but unequal on the two sides, and take origin either from the basilar trunk or from the vertebral, varying through a range of 4 cm. One sees always clearly the external superficial branch which descends in a sinuous course in the direction of the amygdala, without reaching its pole, and therefore is not of any very great value for orientation. The other lateral branches of the basilar trunk are hardly seen from this direction because they are covered by the mass of the petrous bone, with the exception of the superior cerebellar arteries, of which the origin is remarkably fixed and symmetrical on the basilar trunk just before its termination. One can see clearly their passage around the cerebral peduncle parallel to that of the posterior cerebral arteries.

The posterior cerebral arteries, of which we have seen the origin in the interpeduncular space, are seen throughout their extent in this view. At their origin they give rise to the oblique thalamo-perforating arteries. In their first third, the circumpeduncular, they are a little concave superiorly, to the region of the pineal body, where the posterior choroidal artery separates. It is always visible, extending obliquely above and forward, curvilinear with an anterior concavity. This vessel tells one the situation of the choroidal sheet of the posterior part of the roof of the third ventricle as far as the foramen of Monro. In its second third the posterior cerebral artery is almost straight or slightly concave upwards. It continues in the general direction of the first segment, generally perpendicular to the basilar trunk. It gives off here its temporal branches destined for the inferior face of the temporal lobe which, in this view, are superimposed on the branches of the superior cerebellar artery. The last third, in which there is the occipital branching, destined for the inferior surface of the lobe, prolongs the direction of the trunk. Those destined for the internal surface deviate upwards, outlining the anterior border of the cuneus.

The lateral arteriogram, therefore, gives us evidence concerning: (1) the brain stem, the preprotuberal cisterns, the interpeduncular cisterns; (2) the situation of the pineal body and the quadrigeminal tubercles; (3) the state of the roof of the third ventricle; and (4) the cuneus of the occipital lobe.

The fronto-occipital views give a very bad picture of the basilar trunk, lying in about the same direction. They give a projection on the plate which is almost a point. We think that there is very little to be gained from the form of the basilar trunk as it is seen from this direction. In fact, it has a

variable origin, most often at the level of the bulboprotuberential fissure, rarely in the midline, and sometimes even lateral. The course is rarely rectilinear; most often sinuous, nothing fixed, nothing regular, nothing that can serve to orient one.

On the contrary, the point of division of the basilar trunk is always strictly in the midline. This is by far the most important sign perhaps in all vertebral angiography, as Sergent *et al.*[8] have insisted. The view from this angle shows the situation of this point admirably. Moreover the posterior cerebral arteries are seen in all of their extent. One sees clearly the curve that they make around the cerebral peduncles, trapezoidal in form, never closed posteriorly, and superimposed on the more regular ring of the superior cerebellar arteries. The temporal branches are easily visible, and also the occipital branches. They, however, are so sinuous that they cannot have the value that, for example, the anterior cerebral arteries in the carotid angiogram have in indicating the midline.

An arteriogram taken from the direction recommended by Worms and Bretton, therefore, gives information principally on the situation of the cerebral peduncles, of the ambient cistern and of the interpeduncular cistern, and also of the postero-inferior part of the cerebral hemispheres. Plates taken as recommended by Hirtz do not give a good image of the basilar trunk; as we have seen, aside from its point of division, it has little topographical significance. As a matter of fact, we use it only in searching for vascular malformation of this trunk and its collateral branches.

THE PHLEBOGRAM

The phlebogram has not retained our attention as much as the arteriogram. It gives a variable opacification, intense in those veins that receive blood only from the vertebral, such as the cerebellar veins, and on the contrary, often very obscure in the superotentorial veins, in which there is a mixture of blood draining from the carotid territory and the vertebral territory. Cerebellar veins running on the surface of the hemispheres defy any radiological description; the same is true of the superficial occipital veins which form often a star centered by a granulation in the neighborhood of the lambda. The deep veins are more important. One sees clearly, especially in profile, the posterior part of the veins of Galen, lying in the choroidal roof of the third ventricle. They unite, in the neighborhood of the pineal body, with the basilar veins at the end of their circumpeduncular course, of which one sees well the last centimeter. The curve formed by Galen's ampulla, around the splenium of the corpus callosum, is always clear, whereas the straight sinus at the summit of the tentorium, which forms its continuation, is less visible. One can see also the last centimeter of the inferior longitudinal sinus, the last quarter of the superior longitudinal sinus, and the lateral sinus, of which one, usually the left one, always is seen better than the other in the fronto-occipital view.

The phlebogram tells us, therefore, principally about the splenium of

the corpus callosum, the posterior part of the third ventricle, the pineal body and the quadrigeminal tubercles, and the tentorium of the cerebellum. If, now, we group all of the information that the vertebral angiogram can give us, we are in a position to diagnose a certain number of neoplasms lying in the territory of this artery, as will be shown by several examples.

PATHOLOGICAL VERTEBRAL ANGIOGRAPHY

The illustrations in this section have been taken from the writer's thesis.[4] A certain number of these angiographies were made in the service of Professor Alajouanine, whom we wish to thank for the interest that he has always manifested in our technique. Some of the photographs have been retouched, as will be evident from the reproductions.

1. *Vascular Malformations.* They are evidently the major indication for angiography. They do not need explanation, but often necessitate plates taken from several directions in order to show them clearly.

Case 1. Cerebellar angioma, involving especially the vermis (Fig. 1). Beyond surgical help. (Patient of Professor R. Garcin.)

FIG. 1

2. *Tumors in the Angle.* Most of the triumphs of vertebral arteriography concern them. We shall not describe new-formed vessels, which are always variable in their existence and significance. But the pathognomonic sign of a tumor in the angle, in the anteroposterior view, is the lateral displacement

of the point of division of the basilar trunk. This is never absent and betrays a tumor of the angle, accompanied always by more or less evident deformation of the peripeduncular arch. A lateral view will enable one to appreciate a prepeduncular extension of the tumor. Though usually the diagnosis of a tumor in the angle needs no complementary examination, there are cases, nevertheless, in which these examinations are not useless, especially those in which there are very few symptoms. However, vertebral angiography has given us help in indicating the extent of a tumor that was not evident from the symptoms, especially by demonstrating that there was a recurrence of the tumor in a case of meningioma previously operated upon and which had again given trouble.

Case 2. Typical anteroposterior view of the deformation of the arterial system caused by a tumor of the cerebellopontine angle (Fig. 2). The point of division is pushed laterally; the vascular fork is deformed in a characteristic fashion by a neurinoma of the trigeminal.

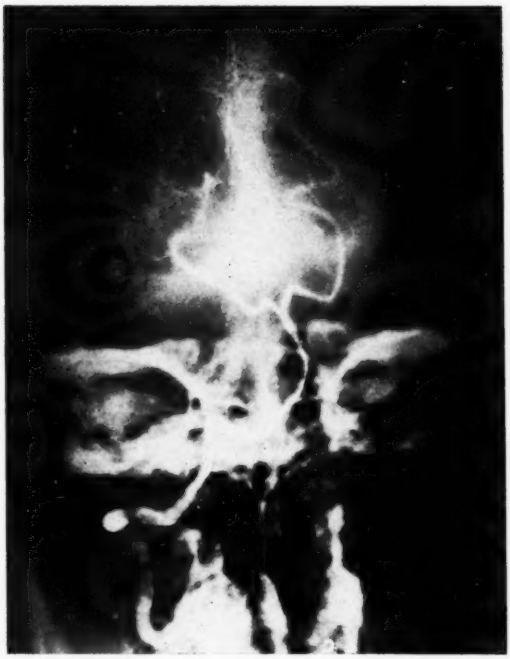

FIG. 2

Case 3. An acoustic neurinoma, the diagnosis of which was doubtful. Angiography brought proof of displacement of the point of division of the basilar trunk and a slight deformation of the arterial fork (Fig. 3).

Case 4. Lateral view (Fig. 4), of which the interest is to demonstrate the unusual

FIG. 3

preprotuberal development of a tumor, seemingly well lateralized on the antero-posterior plate. It was a very large cholesteatoma.

3. *Supra- and Retrosellar Tumors.* These are very easily demonstrated by vertebral angiography in lateral plates.

Case 5. Enormous posterior displacement of the terminal portion of the basilar trunk and the origin of the posterior cerebral arteries (Fig. 5) in a case of benign tumor of very slow development (20 years), possibly a chordoma. No indication for operation.

4. *Pinealoma.*

Case 6. The tumor occupies the seat of the pineal body and is partially injected (Fig. 6). In addition, it deforms the posterior cerebral artery, displacing it downward and stretching it. Diagnosis verified.

5. *Stenosis of the Aqueduct.*

Case 7. The first two thirds of the posterior cerebral artery are stretched and pushed downward (Fig. 7). It is a sign of hydrocephalus, just as the unrolling of the anterior cerebral artery.

FIG. 4

FIG. 5

FIG. 6

FIG. 7

6. *Tumor of the Cerebellar Hemisphere.* These tumors are the sources of great disappointments with our method. There are no angiographic signs which permit one to tell which is the hemisphere invaded by the tumor.

Case 8. A least there exists an indirect sign of a cerebellar tumor—the unrolling of the principal arterial trunk, which loses its habitual triple curvature (Fig. 8). The vertebral and the basilar trunk form a regular course, continuing from the atlas to the clinoid process, and are pushed against the clivus; there is no preprotuberal cistern. This was a cystic hemangioma.

FIG. 8

7. *Meningioma of the Tentorium.*

Case 9. The tumor is injected during the arteriolar phase. It can be seen above and below the tentorium (Fig. 9). Moreover the vessels are deformed. In this case angiography was particularly valuable. It confirmed the diagnosis of a tumor and outlined its extension exactly (both above and below the tentorium). Also it diagnosed the nature of the growth. Only a meningioma is injected thus, with a certain retardation during the arteriolar phase.

8. *Thrombosis of the Posterior Cerebral Artery.*

Case 10. Angiogram (Fig. 10) of a man who had sudden development of complete paralysis of the right oculomotor nerve. The anteroposterior plate shows interruption of the right posterior cerebral artery where it crosses the third nerve. Carotid angiography done subsequently did not inject the posterior cerebral artery; we wished to be sure that we were not dealing with an anomaly. The vertebral angiogram made a week later showed the same image. The condition, therefore, was not a spasm but a thrombosis.

FIG. 9

FIG. 10

9. *Thrombosis of the Right Internal Carotid Artery.*

Case 11. In the course of a typical vascular syndrome of the anterior cerebral artery, a carotid injection was made on the right side. The injection stopped at the base of the cranium—the characteristic aspect of a thrombosis. The injection of the other carotid artery showed that it did not have a functional anastomosis. We then performed vertebral angiography (Fig. 11) which explained the mystery of this syndrome, showing that the Sylvian system was almost totally supplied by the vertebral and the posterior communicating artery, whereas nothing passed into the territory of the anterior cerebral.

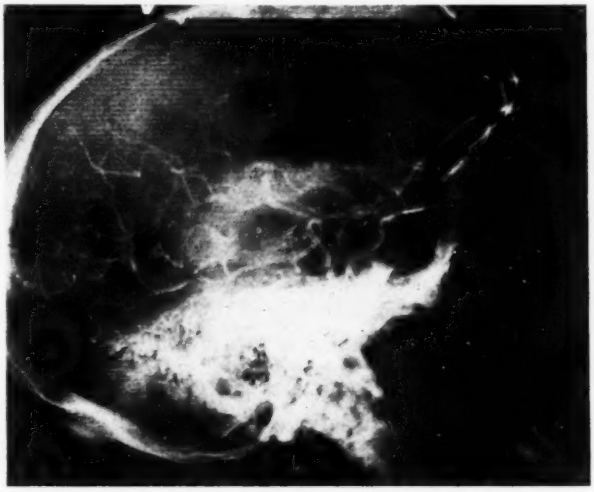

FIG. 11

Comment. It is not possible here to multiply these examples indefinitely. However, it may be added that vertebral angiography permitted us to localize an occipital abscess and to demonstrate the posterior development of a large hypophysial adenoma; and to discover one of those cases of abnormal communication between the vertebral and the carotid at the base of the skull, which is an embryological rarity.

ACCIDENTS

To practice vertebral angiography does not seem to us to be a dangerous method if one follows the proper indications and observes certain rules. In making 160 angiographies, however, we have observed 4 serious accidents, of which 2 were mortal. A fatal accident occurred in 1949. The operator, having demonstrated that there was a spasm with the first plate, injected 5 cc. of novocain, 1–100, in the artery. Immediately there appeared a paleness of the face, profuse sweating, vomiting, and irregularity of the pulse and of respiration. Finally a profound coma developed which after a few hours resulted in death. Autopsy did not show any appreciable lesion.

We must attribute the fatal accident to the intra-arterial injection of novocain. Therefore we have never repeated this procedure.

The second accident occurred after an arterial angiography in a young man with a left hemianopsia, with no vascular hypertension. A few minutes after the injection the patient entered into a coma and remained so for several hours. There was a left hemiparesis which later disappeared entirely. Angiography did not show any vascular displacement. The opposite vertebral artery was injected in retrograde fashion, showing that there had been an excessive pressure in the course of the injection. For this reason we have made it a dogma not to inject with any great pressure.

The third case concerned a left hemiparesis. It was found in the morning following a vertebral angiography made in an attempt to determine the cause of a meningeal hemorrhage which had developed a month before, the carotid angiography having shown nothing. Hemiparesis disappeared rapidly in the following days. The genesis of this accident is mysterious. There seems to have been no fault in technique and the vertebral angiography did not show any lesion.

The fourth case concerned an elderly subject, arteriosclerotic, with a right hemiparesis and hemianopsia. The procedure passed without any untoward incident. Three days later, there appeared a state of shock, anxiety, precordial pain, air hunger and lowering of the arterial tension. We thought of a myocardial infarction but the autopsy did not confirm this diagnosis. Necropsy showed retraction of the mitral valve with calcification and old softening of the left cuneus. Whatever may have been the part of the angiography in the mechanism of this late fatal accident, it is unquestionable that the cardiovascular state of this patient should have made us renounce such a test. So we believe that, of these four grave accidents, three could have been avoided, the first one by correcting an error of technique, the last one by avoiding an error of indication.

CONTRAINDICATIONS

These are the same as for carotid angiography on which Petit-Dutaillis, Pertuiset and Rougerie[5] have insisted in a former article. Certain of them are formal: hypertension, renal insufficiency, and diffuse vascular sclerosis of those with coronary disease. Also asthma should make one fear allergic reactions to iodized products.

CONCLUSIONS

The author believes that percutaneous vertebral arteriography is not simply a feat of technical prowess but that it can render numerous real services, sometimes irreplaceable, and that it is relatively benign, if one makes the injections gently. It is certain that we can hope for more important information as we accumulate a larger series. So it is believed, in spite of the prejudices of certain persons concerning this method, that it must figure from now on in the arsenal of every neurosurgical service among the complementary methods of investigation.

SUMMARY

In the light of 162 percutaneous vertebral angiographies made since 1948 in the neurosurgical clinic of the Pitié, the author describes a personal procedure of percutaneous approach at the base of the skull and lays down the bases for a normal radiological anatomy, showing what there is that is fixed and certain in the relations of this artery, which is so variable. With the aid of several examples he describes the most characteristic pathological aspects, insisting notably on the value of vertebral arteriography in the diagnosis of tumors in the region of the cerebellopontine angle and of the clivus. He insists on the relative benignity of this examination, if one observes certain precautions that are the rule in surgical circles.

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CONTROLLED TRANSORBITAL LEUKOTOMY

WILLIAM A. NOSIK, M.D.*
Cleveland, Ohio

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IN VIEW of the large numbers of transorbital leukotomies being performed it is apparent that this operation is gaining in recognition, and may well account for approximately one-third of the lobotomies performed, according to Freeman and Watts.[3] In his appraisal of this procedure, which he has used in 300 cases, Moore[6,7,8] was of the opinion that it possesses a great advantage over other methods of lobotomy in that there are no untoward psychological effects, there is an ease of performance, the hospitalization period is short and nursing care is minimal, the morbidity is insignificant, the mortality rate is low (1.8 per cent), and the results are as favorable as those obtained with other more extensive operations. Moore urged a greater utilization of this operation in suitable cases. Wilson and Pittman,[10] after their study of 200 cases, recommended transorbital leukotomy for all chronically disturbed patients when less strenuous forms of treatment have failed after 1 year's trial. It is apparent also from an abundant literature that prefrontal lobotomy has certain ameliorating tendencies in the care of the patient with intractable severe pain, whether or not the procedure is done through a trephine in one of various positions, or through the transorbital route.

In discussing transorbital lobotomy Williams and Freeman[9] felt that the morbidity and mortality statistics of this operation are encouraging. Fifteen brains were studied up to 1 year after such an operation. These authors concluded that from a pathological standpoint, the operation is a clean-cut, selective procedure for severing the thalamofrontal radiations. Fulton,[4] on the other hand, believed that the operation of lobotomy removes large numbers of visceral pain projections from the sphere of consciousness, which accounts for the patient's change in attitude towards his pain. Balakrishna Rao[1] claimed that lobotomy is more effective in patients with marked psychic pain, which favors the opinion of most writers that the benefits of psychosurgery result largely from relief of the anxiety and fear of the future and from the euphoria produced. Fulton[4] believed that radical lobotomy should be abandoned in favor of a more restricted lesion. Several more limited procedures have been recorded in the literature. Grantham,[5] for example, stated that good results were obtained in a series of patients with severe pain when the pathways in the lower mesial quadrants were interrupted. It appears that the present trend is toward a more selective or restricted operation.

This discussion does not concern itself with the pros or cons of prefrontal lobotomy either in psychosurgery or the pain problem. Neither is it a discus-

* 10515 Carnegie Avenue, Cleveland 6, Ohio.

sion claiming greater effectiveness in the solution of either of these problems by surgical methods. Rather, it is concerned with the presentation of another method of attacking the same problem with more regard for the patient's safety, yet achieving the desired clinical result. The leukotomy is converted to a more precisely controlled operation which leaves a set of data in each case available for future study and analysis. An attempt has been made to make this particular operation less of a blind procedure than it has been heretofore. A specially designed transorbital leukotome, under x-ray control in its positioning and manipulation, was used. This leukotome (Fig. 1) consists of a hollow steel rod with a blunted tip, having within its lumen a steel

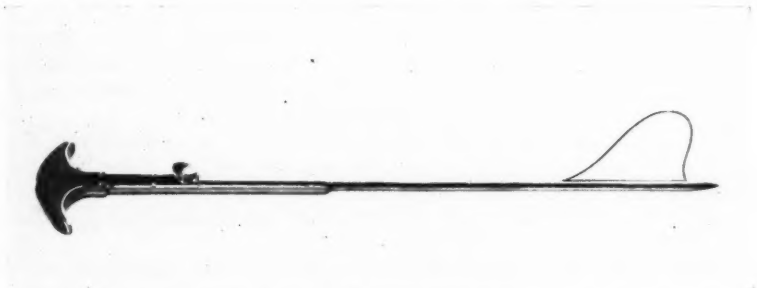

FIG. 1. Oblique view of the specially designed transorbital leukotome, with the cutting loop fully extended. By pulling backward on the knob the cutting wire disappears into the visible slot.

wire capable of being extruded through a slot to expand into a cutting loop of a predetermined variable size, and controllable at the gripping end of the tool. The tip of the leukotome is deliberately left blunt so that, while capable of penetrating the orbital plate, it would tend to push aside any vessel encountered in its course without lacerating it. A lateral cutting of the white substance is done with a thin wire loop which is easily deflected by any vessel encountered. This inner cutting wire is replaceable. Should a vessel be inadvertently encountered and ruptured, the operator would be immediately apprised of this fact by the flow of blood down the lumen of the instrument. This has not been encountered to date. The lateral extension of the expanding loop is measurable in centimeters upon the handle of the instrument.

PROCEDURE

This operation is considered only after x-ray study of the head and orbit has been made to eliminate those factors that could be complications in the use of the transorbital approach. As summarized by Fiamberti[2] they are: (1) aberrant ethmoid cells with infection, (2) malformations or thickening of the orbital plate, (3) osteomas of the orbital plate, and (4) intraorbital tumors. Having determined that none of these situations exists, the patient is prepared for surgery in the usual manner, though obviously no special head preparation is necessary. The operation is carried out in the operating room if a

good portable or stationary x-ray unit is available in the room. However, the procedure can be equally well done on the regular x-ray table.

A general anesthetic is used, usually pentothal, and these successive steps are followed:

(1) The patient is draped under sterile conditions, leaving only the eyes exposed.

(2) The eyelid is elevated and the leukotome is placed somewhat posteriorly against the floor of the orbit in a position corresponding to the approximate center of the pupil.

(3) With an assistant steadying the head and aiming the instrument toward the coronal suture the orbital plate is penetrated with several sharp blows of a surgical mallet.

(4) During these procedures the wire is, of course, left flat in its canal and the leukotome is driven in until, in the operator's opinion, it rests approximately 2 cm. below the inner table of the skull. Because of the variability of the soft tissue about the orbit no definite measurements can be given as to the exact penetration necessary to accomplish this since it varies from person to person.

(5) At this point lateral and AP views are made with the roentgen unit, the wet films being returned as promptly as possible, and the position of the leukotome is adjusted according to the degree of error made in its placement. The relation of the leukotome to the medial plane and to the lateral and anterior inner tables of the skull is noted and measured.

(6) When a coronal section is desired the handle of the instrument is rotated nasally until the slot is directed along the desired coronal plane. The small knob on the butt of the instrument is then pushed forward 2 or 3 cm., noted on the handle, to expand the loop to a corresponding degree, thereby cutting the white matter. Should the measurements of the skull reveal that complete cutting cannot be done in this fashion, the instrument can, of course, be angled over toward the medial plane as desired. An AP roentgen film is taken as a permanent record of the exact location of the extent and position of the medial transection and the instrument is returned to the midline.

(7) To complete the lateral wing of the coronal section the slot which had been directed medially is now rotated through 180 degrees to point directly laterally without changing the angle of entrance through the orbit. The loop is again expanded to the desired extent and another AP roentgen film is made to record the position and extent of the transection. This completes the section of the median-lateral superior quadrants.

(8) From the original films it is apparent that if a coronal section of the inferior mesial or lateral quadrants is desired or an undercutting, as for example, of the frontal region, the leukotome must be withdrawn until the lower edge of the slot is approximately 2 cm. from the floor of the orbit. This done, the same procedure is followed as was enumerated above, though in some instances it may be necessary to expand the loop farther. Films are made in these positions as previously mentioned so that an accurate record may be obtained of the areas traversed by the wire.

(9) The loop is then returned to its initial position and retracted into the tube.

(10) The leukotome is then returned to its initial position. Should it be desired to undercut the frontal surface anteriorly, the loop is expanded to the desired number of centimeters obtained from the measurements made on the films and a lateral exposure is made to record the position of the instrument. If this is satisfactorily placed the loop is then swung nasally through a 90-degree arc, then back to its

initial midline position. A lateral swing through 90 degrees is made to complete the frontal undercutting.

(11) When two leukotomes are available it is apparent that the time of this procedure could be shortened by virtue of doing both sides at once, thereby obviating the necessity of another set of x-ray films. Should only one be available, the same procedure as outlined above is carried out on the opposite side.

(12) On completion of the procedure the loop is, of course, retracted and the leukotome is removed from the orbit. Firm pressure is kept at the penetration site for several minutes to minimize the ecchymoses noted in some patients.

(13) Pressure dressings of elastic type are placed over the orbit and removed in several hours. Antibiotics are usually given and the patient is returned to bed with the head in an elevated position. Lumbar puncture has been done immediately postoperatively in most of the patients to obtain a definite record of the immediate postoperative situation with regard to the pressure, the color of the fluid, etc. The patient is permitted to be ambulatory the following day and returned to a routine diet.

DISCUSSION

Most neurological surgeons of any experience are somewhat fearful of a so-called "blind" surgical procedure wherein the operative field is not under direct vision—a view that is wholeheartedly endorsed here. However, it is likewise recognized that even as a blind operation, transorbital lobotomy is apparently increasing in popularity—particularly since the morbidity and mortality statistics compare favorably with those of other similar procedures and because of those advantages mentioned earlier in this paper. In order to gain such advantages as this particular procedure may have over others, the effort has been made here to give the operator better control of the surgical situation. While the mortality is low, it is believed that by more adequate control it can be reduced still further without detracting from any of the desirable features of the operation. By using a special leukotome it is apparent that a finer incision line with less local destruction of tissue can be made than that produced by a coarse tip which tears a relatively wide pathway through the brain. It is also evident that this incision line can be projected much farther than by the ordinary leukotome even when it is swung through the arcs described by Freeman. In certain orbitofacial configurations it is virtually impossible to swing the ordinary leukotome far enough medially or laterally to effectively section any but a relatively small arc of tissue without fracturing the orbital plate which would be, of course, a somewhat primitive way of attaining a desired result.

Radiographic control, not only of the placement but of the manipulation of the leukotome, is felt to be of great importance. It is interesting to note how, when the ordinary landmarks are followed, a surprising degree of adjustment of the leukotome is often necessary before it is properly located. Should the lobotomy have been carried out in some of the positions noted, an effect far less than desirable would have resulted, and detracted considerably from future interpretations of the efficacy of such an operation. With the use of x-ray control the operator is left with a permanent record of the

tissue planes transected. In all, some 32 operations of this type were performed with no mortality that could in any way be attributed to the operative procedure. The method outlined was followed as described and has proved to be quite satisfactory. It is apparent, moreover, that this technic can likewise be applied to the standard lobotomy done through a trephine opening, with this leukotome being used in place of the standard leukotomy blade, much in the manner suggested by McKenzie. As mentioned before, should a vessel be inadvertently torn, it is believed that the most reasonable course would be to allow the leukotome to remain in place and permit the blood to drain through it until such drainage has stopped. Should the hemorrhage be of greater proportions the location of the leukotome (if left in place) would serve as an effective guide in finding the bleeding point from above.

When this operation of lesser proportion than the standard prefrontal lobotomy is proposed, using this particular technic, it is believed that a greater degree of safety is afforded the patient. It is likewise believed that a more restricted and selective lesion may be effected to gain the desired clinical result.

CONCLUSIONS

(1) A method of transorbital leukotomy is described, wherein a specially designed leukotome is used to produce a selective and more restricted lesion under x-ray control.

(2) In contrast to the previously used "blind" approach, it is believed that greater accuracy and safety can be assured the patient in the production of the surgical lesion.

(3) A more accurate permanent record can be obtained to aid in future correlation studies between the size and position of the lesion produced and the result obtained.

(4) If the transorbital operation is selected as the operation of choice in a given case, the controlled procedure is considered more desirable than the "blind" one.

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THE USE OF ACTH IN CONJUNCTION WITH SURGERY FOR NEOPLASMS IN THE PARASELLAR AREA*

JOHN RAAF, M.D.,† DONALD L. STAINSBY, M.D.,‡
AND WILBUR L. E. LARSON, M.D.†
Portland, Oregon

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ALERTING the medical profession to early diagnosis is probably the most important factor in lowering operative mortality attending surgery for parasellar neoplasms. Various authors attest the hazards of surgery after the tumor has become large. Horrax[5] stated that as pituitary tumors extend out of the sella to become intracranial tumors, the risk of operation increases from 3–5 per cent to 30 or 40 per cent. Jefferson[7] as well as Bakay[1] reported somewhat comparable figures. Similarly, danger accompanying removal of other types of tumors in this area increases with the size of the neoplasm.

The use of drugs[10] to lower blood pressure during the removal of large vascular tumors such as sphenoidal ridge meningiomas has been of great help in decreasing operative mortality. Antibiotics and chemotherapy as well as close attention to fluid and electrolyte balance have also materially aided in smoothing the postoperative convalescence. Tracheotomy has been a life-saving factor in some cases of desperately ill patients.[3]

From our experience with 18 patients with parasellar tumors we believe that ACTH is another valuable adjunct to surgery in this area. It is well known that operation in the parasellar region is dangerous because of the proximity of the pituitary body and the hypothalamus. The normal pituitary-adrenocortical response to stress may be depressed if the area is damaged by the tumor growth prior to surgery or through trauma at the time of operation.

Roche, Thorn and Hills[9] mentioned the use of ACTH in Matson's patient who was operated upon for pituitary tumor. Caughey, James and MacLeod[2] stated that marked improvement occurred after they administered cortisone and ACTH to a stuporous patient who had been operated upon for chromophobe adenoma. Another patient in their series with acromegaly failed to arouse following surgery. Beginning on the third postoperative day cortisone was given with marked improvement in 28 hours. The course during and after surgery in patients operated upon for craniopharyngioma was stabilized with cortisone and ACTH according to Ingraham, Matson and McLaurin.[6]

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† University of Oregon Medical School, Portland.
‡ Eugene, Oregon.

REPORT OF CASES

That ACTH might be an important component in smoothing the postoperative course of patients with tumors in the parasellar region, particularly those who displayed signs of hypopituitarism, was first brought to our attention through the following case.

Case 1. P.H., a male aged 20, presented himself on Nov. 16, 1950, with the complaint of difficulty with vision for 10 days. Since 1948 he had suffered from headaches which occurred intermittently, sometimes as often as two or three times a week. He had noted no difficulty with his vision until he awakened in the morning of Nov. 6, 1950, and noticed that he could see only half of some objects. Inquiry revealed that he had never shaved, but he thought there was no loss of sexual libido or potentia.

Examination. He was pudgy and pallid, and showed unmistakable signs of hypopituitarism. He had a high-pitched voice, and scanty axillary and pubic hair. The genitalia were small and the testicles were soft. He had bitemporal hemianopsia and an enlarged sella turcica.

Operation. On Nov. 21, 1950, through a left frontal approach to the pituitary fossa, an intracapsular removal of the tumor was carried out and a large portion of the capsule was removed. Retraction of the left frontal lobe to expose the tumor resulted in no demonstrable trauma to the brain, and the patient left the operating table in excellent condition.

Microscopic Diagnosis. The tissue removed was chromophobe adenoma of the pituitary.

Postoperative Course. For the first 24 hours his condition was very satisfactory. At the end of 24 hours edema of the face and head was exceptionally marked. Within 36 hours after operation his temperature had risen to 104° and his blood pressure had started to climb. Rapidly thereafter he became drowsy and his condition deteriorated. Late on the 2nd night after operation he suddenly stopped breathing. An endotracheal tube was at hand and was quickly inserted; he was taken to the operating room under artificial respiration.

Elevation of the bone flap revealed very little extradural or subdural hematoma and no evidence of an intracerebral hemorrhage. The brain was so tightly swollen it was difficult to elevate the frontal lobe to expose the chiasmal area. Amputation of the tip of the left frontal lobe allowed examination of the chiasm but there was no hematoma in that region, and swelling of the brain was thought to be the cause of his difficulty. A decompression and a tracheotomy were done. The patient was returned to his room in poor condition.

ACTH, 25 mg. intramuscularly every 6 hours, was started immediately and the patient rapidly improved. No doubt there were other factors such as the decompression and the tracheotomy that facilitated his rapid recovery but there seemed little doubt that ACTH played a role.

The rapid recovery of this patient who was so desperately ill led us to believe that other patients, particularly those showing evidence of hypopituitarism, would tolerate surgery much better if prepared with ACTH. It was decided that all patients with tumors in the parasellar area would be given ACTH before and following operation. Between November, 1950 and April, 1954, 17 additional patients with tumors in the parasellar area were

given ACTH in conjunction with surgery. Chart 1 is a brief summary of the 18 cases.

There are 2 cases in the series with no microscopic proof of the nature of the tumor. Case 4 was operated upon elsewhere in 1944. According to report, the signs, symptoms and microscopic findings were typical of chromophobe adenoma of the pituitary. When he began to lose visual fields again he was re-explored by one of us. Adhesions rather than recurrence of tumor were producing contraction of fields. Case 13 was the other patient from whom no tissue was removed. Before surgery visual field examination and roentgenographic evidence of a greatly enlarged sella turcica indicated a chromophobe adenoma of the pituitary. The loss of visual fields was minimal but the patient complained greatly of double vision; therefore, operation was undertaken. At operation there appeared to be a chromophobe adenoma situated far posteriorly. Since the surgeon thought the lesion might be an aneurysm, closure was made without removal of tissue. Arteriograms immediately after operation proved there was no aneurysm but rather than re-open the wound, x-ray therapy was given with very satisfactory results. The diplopia disappeared and visual fields became full.

ADMINISTRATION OF ACTH

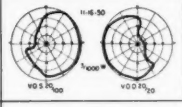
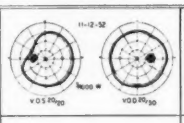
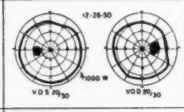
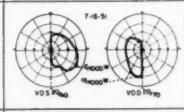
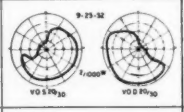
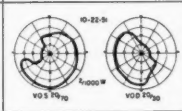
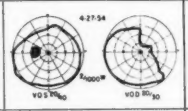
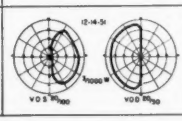
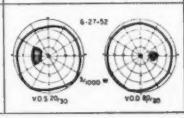
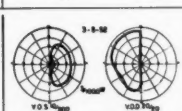
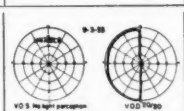
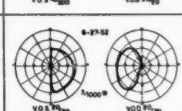
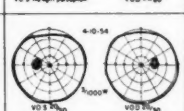
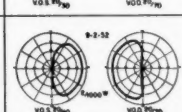
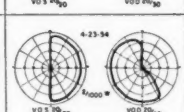
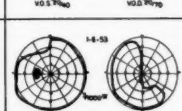
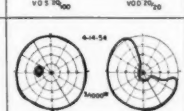
ACTH rather than cortisone was originally selected for administration. Since ACTH is one of the hormones lacking in the hypopituitary patient, and since all of the physiological effects of ACTH are not fully understood, it seemed reasonable to supply the lacking hormone rather than one of the corticosteroids which it stimulates the adrenal cortex to produce. Although it is thought that ACTH should be given for 3 to 5 days to produce the maximum effect, no set rule of administration was employed. Each case was handled on the basis of the individual pre- and postoperative state. Those who were thought to be more severely hypopituitary from a clinical standpoint were given more ACTH both before and after surgery than those who were mildly hypopituitary or those who showed no signs of pituitary hormone loss. Twenty-five mg. of ACTH intramuscularly were administered every 6 hours from 1 to 5 days preoperatively. This dosage was continued through the first 2 to 4 postoperative days, then gradually reduced.

Those patients in the older age group who were thought to have impending cardiac and renal disorders were limited to 1 gm. of sodium chloride intake daily and given 2 gm. of potassium chloride orally each day while receiving ACTH. Because of the short period of therapy this might not have been necessary but was done as insurance against some of the unpleasant physiological effects of ACTH.

RESULTS

There were no operative deaths in the 18 consecutive cases. Two of the patients had stormy postoperative courses. One of these (Case 1) has already been discussed. It seems likely that had this patient been prepared with

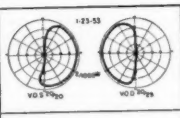
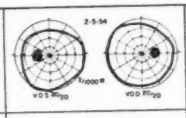
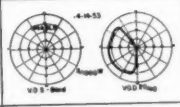
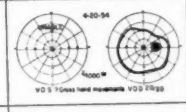
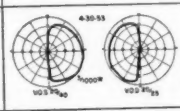
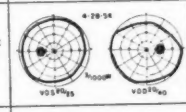
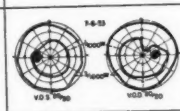
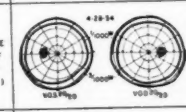
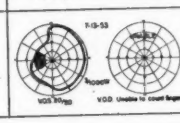
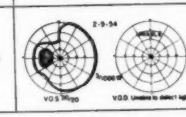
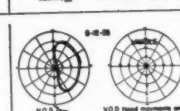
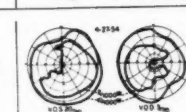
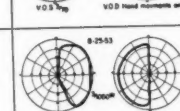
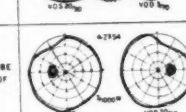
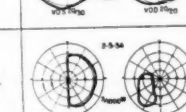
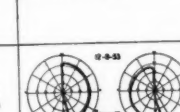
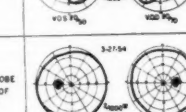
CHART 1

CASE NO. AND PT.	SEX AND AGE, YEARS	VISUAL FIELDS BEFORE OPERATION	OPERATION	MICROSCOPIC DIAGNOSIS	MOST RECENT VISUAL FIELDS	CONDITION UPON LAST CONTACT
1 PH.	M 20		INTRACAPSULAR REMOVAL OF TUMOR 11-21-50	CHROMOPHOBE ADENOMA OF PITUITARY		CONDITION GOOD IN NOVEMBER 1953 WORKING ON FARM
2 L.S.	F 47		SUBTOTAL REMOVAL OF TUMOR 12-28-50	EPENDYMOMA	FIELD EXAMINATION ATTEMPTED 5-2-51 PATIENT UNCOOPERATIVE	IMPROVEMENT AFTER OPERATION LATER GRADUAL FAILURE DIED 9-18-51
3 G.R.	M 59		INTRACAPSULAR REMOVAL OF TUMOR 7-21-51	CHROMOPHOBE ADENOMA OF PITUITARY		WORKING 9-26-52
4 E.B.R.	M 51		RE-EXPLORATION FOR CHROMOPHOBE ADENOMA OF PITUITARY ADHESIONS FREED 10-24-51	NO TISSUE FOR MICROSCOPIC EXAMINATION		WELL AND ABLE TO WORK 4-27-54
5 H.R.	F 43		INTRACAPSULAR REMOVAL OF TUMOR 12-17-51	CHROMOPHOBE ADENOMA OF PITUITARY		ASYMPTOMATIC 6-27-52
6 P.M.R.	M 44		INTRACAPSULAR REMOVAL OF TUMOR 3-6-52	CHROMOPHOBE ADENOMA OF PITUITARY		GREATLY IMPROVED GENERAL CONDITION WORKS ON FARM 9-6-53
7 C.R.	F 52		INTRACAPSULAR REMOVAL OF TUMOR 7-2-52	CHROMOPHOBE ADENOMA OF PITUITARY		TEACHING SCHOOL CONDITION EXCELLENT 4-10-54
8 L.M.	F 43		INTRACAPSULAR REMOVAL OF TUMOR 9-9-52	CHROMOPHOBE ADENOMA OF PITUITARY		DRIVING CAR NO SERIOUS COMPLAINTS 4-23-54
9 H.E.M.	M 29		INTRACAPSULAR REMOVAL OF TUMOR 1-7-53	CHROMOPHOBE ADENOMA OF PITUITARY		WORKING GREATLY IMPROVED 4-14-54

ACTH before surgery the marked cerebral edema, which almost cost him his life, might have been avoided.

In Case 4 the postoperative course was complicated by large extradural and subdural hematomas. Following evacuation of these he finally made a

CHART 1 (continued)

CASE NO. AND PT.	SEX AND AGE, YEARS	VISUAL FIELDS BEFORE OPERATION	OPERATION	MICROSCOPIC DIAGNOSIS	MOST RECENT VISUAL FIELDS	CONDITION UPON LAST CONTACT
10 C.J.N.	M 25		INTRACAPSULAR REMOVAL OF TUMOR 1-29-53	CHROMOPHOBE (EOSINOPHILIC) ADENOMA OF PITUITARY		NO COMPLAINTS 2-4-54
11 G.R.	F 52		TOTAL REMOVAL OF 8 CM SPHENOIDAL RIDGE TUMOR 4-20-53	MENINGIOMA		FEELS WELL 4-20-54
12 A.C.	F 64		INTRACAPSULAR REMOVAL OF TUMOR 5-13-53	CHROMOPHOBE ADENOMA OF PITUITARY		MUCH IMPROVED EYE SIGHT BETTER 4-28-54
13 A.J.H.	M 47		UNABLE TO REMOVE	GROSSLY CHROMOPHOBE ADENOMA OF PITUITARY (NO TISSUE)		CONDITION GOOD (POST RADIATION) WORKING IN WOODS AND SAWMILL. 4-28-54
14 I.L.W.	M 24		SUBTOTAL REMOVAL OF TUMOR 8-5-53	CHORDOMA		EXAMINATION FOR MARRIAGE LICENSE WORKING AND WELL 4-19-54
15 A.M.P	M 51		SUBTOTAL REMOVAL OF TUMOR 8-19-53	CRANIO-PHARYN-GIOMA		DRIVES CAR PLAYS GOLF WORKS AT REGULAR JOB 4-27-54
16 E.T.	F 46		INTRACAPSULAR REMOVAL OF TUMOR 9-10-53	CHROMOPHOBE ADENOMA OF PITUITARY		NO LONGER HAS HEADACHES EYES MUCH IMPROVED 4-27-54
17 F.M.P.	F 11	PATIENT HAD BITEMPORAL HEMIANOPSIA FIELD SHEET LOST.	SUBTOTAL REMOVAL OF TUMOR 10-19-53	CRANIO-PHARYN-GIOMA		DOING WELL GOING TO SCHOOL 4-9-54
18 F.L.W.	M 44		INTRACAPSULAR REMOVAL OF TUMOR 12-14-53	CHROMOPHOBE ADENOMA OF PITUITARY		NO COMPLAINTS 3-27-54

good recovery and when last seen on April 27, 1954, he was well and able to work.

Particularly gratifying was the postoperative course in Case 10. This patient was a typical acromegalic (Fig. 1). Grant[4] had no operative deaths

among 10 patients (craniotomy approach) with eosinophilic tumors, 6 of whom showed definite signs of acromegaly. Naffziger[8] reported that in their clinic operation upon acromegalics by the transphenoidal route carried an operative mortality of 6.6 per cent. However, in the past it has been our opinion that in an acromegalic an intracranial operation for removal of a pituitary adenoma is particularly hazardous mainly because of postoperative cerebral edema. In our acromegalic patient prepared with ACTH swelling of the face after operation was minimal, recovery was very rapid, and he left the hospital on the 6th postoperative day.

Observation during the postoperative convalescence of this group of patients with parasellar tumors indicated that administration of ACTH is likely to be followed by these results:

(1) The patient has a sense of well-being and alertness.

(2) The postoperative temperature curve is lower than in patients who have not received ACTH. In 8 of the 18 cases the temperature did not rise

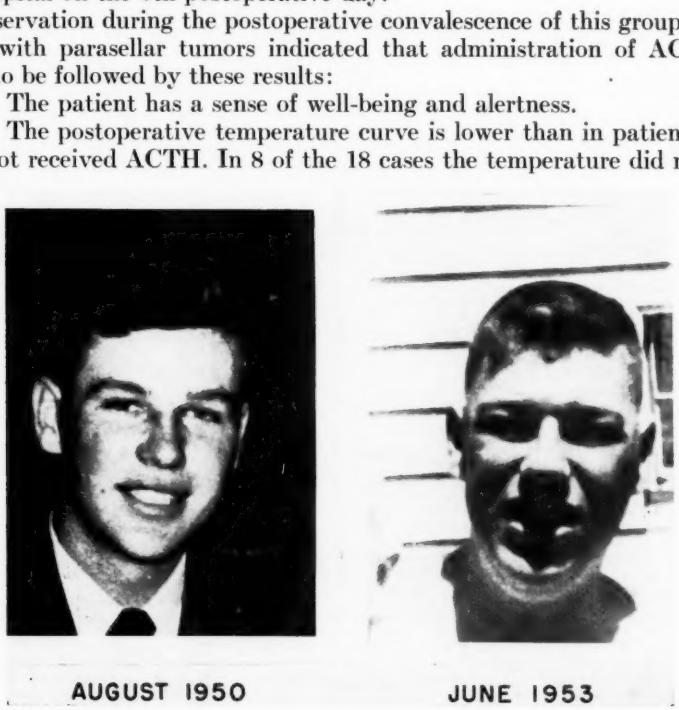


FIG. 1

over 101° at any time during the convalescence. Only 1 of the 18 patients had a temperature over 103° in the postoperative period. In Case 4, following evacuation of a postoperative hematoma, the temperature rose to 104.4°.

(3) Facial edema, which might reflect the degree of cerebral edema, is less when the patient is prepared with ACTH. It seems likely that control of cerebral edema is one of the chief reasons for the smooth postoperative convalescence.

While one of the patients in this series left the hospital on his 6th postoperative day and our impression is that by the use of ACTH the average

hospital stay would be reduced, it is difficult to make a definite statement because many of the patients were kept in the hospital for postoperative radiation therapy.

COMMENT

An attempt to explain the reasons why ACTH seems to smooth the postoperative course in patients with frank or impending hypopituitarism leads one into a maze of complicated and obscure physiological effects of the adrenocortical steroid hormones. Adrenocorticotropic hormone (ACTH) is elaborated by the anterior pituitary, the function of which is at least partially controlled by the hypothalamus and in turn this structure is probably under the influence of the higher brain centers. While the medulla of the adrenal gland responds to stimulation from the autonomic nervous system, the adrenal cortex is activated by ACTH, as shown by the increase in urinary excretion of 17-ketosteroids and 11-oxysteroids. The anterior pituitary may also be stimulated to produce adrenocorticotropic hormone by epinephrine which is released from the adrenal medulla in response to stress.

Among the many corticosteroids produced by the adrenal cortex, two are cortisone (Kendall's Compound E) and hydrocortisone (Kendall's Compound F). A responsive adrenal cortex is necessary for ACTH to be effective, while cortisone has the advantage of effectiveness irrespective of the condition of the pituitary-adrenal system. On the other hand, sudden withdrawal of ACTH does not lead to adrenal insufficiency as is sometimes seen in sudden withdrawal of cortisone.

In using ACTH rather than cortisone in these cases we of course assumed the patients had functioning adrenal cortex. None of our patients presented the appearance of severe pituitary cachexia, but 10 of our total number of 13 patients with pituitary adenomas showed unmistakable clinical signs of hypopituitarism. Eosinophil counts even in some of the more severe clinical cases of hypopituitarism in this series indicated that the adrenal cortex had not undergone any marked involution and was capable of responding to ACTH stimulation.

If the important factor in promoting the smooth postoperative convalescence in these patients is reduction of postoperative cerebral edema, how may this phenomenon be explained? Cortisone and especially ACTH may bring about retention of sodium chloride and water, and an increase of urinary excretion of potassium. While this may eventually result in frank edema, it was thought that this factor was negligible considering the short time ACTH was administered.

Cortisone and possibly even to a greater extent hydrocortisone have an anti-inflammatory activity at the tissue level. It seems possible that this factor could result in lessening cerebral edema during the acute postoperative period. Cortical steroids seem to depress the reaction of the cells of the body to a noxious stimulus, whether traumatic or bacterial, so that the cells better withstand abnormality.

Possibly another factor in smoothing the convalescence is that the euphoria and increased appetite produced by the administration of ACTH increase the protein intake.

SUMMARY

A series of 18 consecutive patients who received ACTH in conjunction with surgery for tumors in the parasellar area have been reported. ACTH seemed to smooth the postoperative course. Lessening of cerebral edema is thought to be an important if not the most important factor.

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PRODUCTION OF FOCAL DESTRUCTIVE LESIONS IN THE CENTRAL NERVOUS SYSTEM WITH ULTRASOUND*

W. J. FRY, M.S., W. H. MOSBERG, JR., M.D.,†
J. W. BARNARD, PH.D. AND F. J. FRY, M.S.
Bioacoustics Laboratory, University of Illinois, Urbana, Illinois

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With the contemporary development of surgical methods of treating the symptoms of painful, psychiatric, and basal ganglion disorders, the neurosurgeon is frequently called upon to produce a focal destructive lesion in the nervous system. The universal and obvious objective is to create a localized lesion in the desired area with no damage to adjacent or intervening tissues. Recorded experiences of neurosurgeons attest to the fact that this ideal has not yet been attained. Paraparesis and bladder dysfunction following anterolateral chordotomy, vegetation following prefrontal lobotomy, and hemiplegia following surgical treatment of basal ganglion disorders are examples of damage to adjacent tissues known to all neurosurgeons. Damage to blood vessels (including those within the site of the lesion) at time of operation may increase the operative morbidity and render it impossible to evaluate the effect of a focal ablation. Stereotaxically placed electrocoagulative lesions have frequently resulted in death from hemorrhage.

As the result of animal experimentation[1–4,6] we believe that the use of ultrasound in making human focal destructive lesions will overcome some of these objections. A focussed beam of ultrasound can be used to produce selective, accurately localized lesions in the central nervous system which are quantitatively reproducible from one animal to another. Discrete lesions can be produced without destruction of blood vessels. A lesion in the depths of the brain can be effected without disturbance of intervening tissue. Accurate localization is accomplished by focussing a fine beam of ultrasound in the region to be treated. The nature of the destruction depends upon the intensity and duration of the exposure.

The term "ultrasound" refers to sounds whose frequency (pitch) is above the range of human audibility (15,000 to 20,000 cycles per second). Most of the work up to the present time has been accomplished at a frequency of one

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† Department of Neurological Surgery, University of Maryland School of Medicine, Baltimore, Maryland.

million cycles per second. In addition to its frequency a sound is characterized by its intensity (loudness) which is measured in watts/cm.^{2}. The sounds used in producing the lesions to be described are more intense than any sounds that we experience. Indeed the sounds are of a sufficiently high intensity that they must be transmitted through a liquid medium. Sound intensities used in these experiments have been in the range of 50 watts/cm.^{2} to 1000 watts/cm.^{2}.

The sound is generated by a quartz crystal excited electrically to vibrate in resonance. The sound is focussed by a polystyrene lens placed in front of the vibrating crystal. Focussed beams of sound as small as 1.5 mm. in diameter are readily attained. Transmission of the sound from the lens to the tissue is accomplished through physiological saline. This liquid must be degassed by boiling to prevent the formation of bubbles which would interfere with acoustic transmission at the high intensities used in these experiments. The bone overlying the region of the central nervous system through which the sound is to enter must be removed in order to eliminate absorption by the bone, which causes local heating, and to insure a well defined focussed beam in the nervous tissue.

In the animal experimentation to date the animal's head has been supported in a standard stereotaxic apparatus, and the head held rigidly in position in the machine. Localization of the focal spot in the region of the brain to be affected is determined as follows: Before the animal is placed in the apparatus a pointer attached to the irradiator (vibrating crystal, lens, etc.) and coinciding with the focal spot of the irradiator is positioned on the midline of the apparatus and is collinear with the line through the bars which support the skull of the animal at the ears. The coordinate values on the system that supports the irradiator are read corresponding to this ear-bar zero. One can then transform the coordinates from the stereotaxic apparatus to the coordinates of the system supporting the irradiator. The pointer is then removed from the irradiator and the animal is mounted in the stereotaxic machine. The soft tissues are then incised over the appropriate area of the nervous system and the bone is reflected or removed. The dura mater need not be opened. In practice a flanged cap which is used to contain the physiological saline, which acts as a transmitting medium for the sound, is tied to the skin of the animal. At this time irradiation with ultrasound is carried out.

In order to produce a lesion beneath the surface of the brain or spinal cord without damage to intervening nervous tissue, it is necessary to use an irradiator that produces a beam the intensity of which decreases very rapidly as one moves away from the center of the focal point. One of the ways in which this has been realized is by coupling together four single beam focussing irradiators with suitable adjustments to make the four beams intersect at a common point (Fig. 1). Although the distance from the face of the irradiator to the focal point is fixed (7.5 cm. for the irradiator illustrated), the depth of the lesion in the tissue may be varied by moving the irradiator ver-

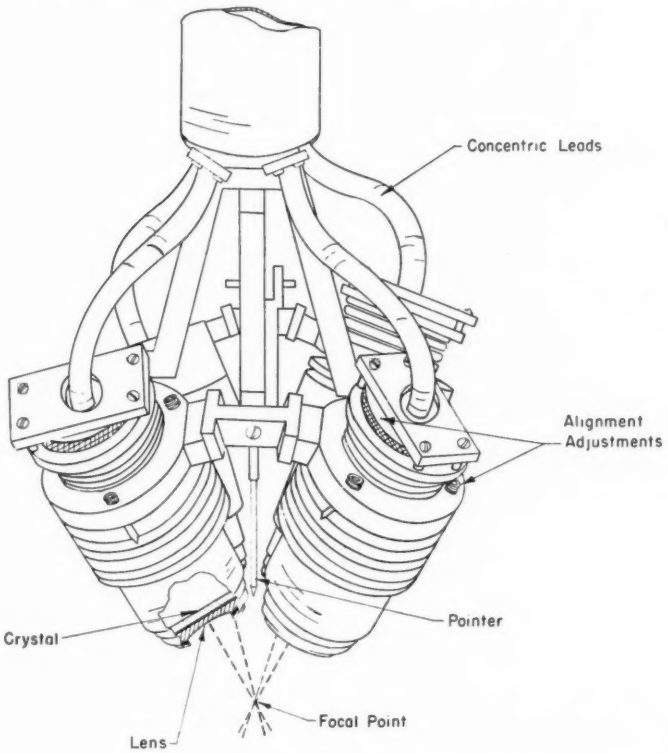

FIG. 1. Schematic diagram of multibeam irradiator.

tically in the saline bath. Accurate relative motion between the stereotaxic apparatus and the focal spot of the sound beam is achieved by having the stereotaxic machine and the coordinate system* that supports the irradiator mounted rigidly on the same supporting table. Fig. 2 shows a close-up view of the multibeam instrument positioned over the head of the animal. The operative bony defect and exposed cerebral cortex may be seen at the depth of the metallic container which is to hold the saline through which the sound beams will be transmitted to the brain. The base of this metallic container is flanged, and this flange is inserted under the skin edges of the incision. In order to realize a water-tight connection between metallic container and scalp in animals we have used a wire tourniquet. Fig. 3 shows the animal positioned in the stereotaxic apparatus with the metallic container in place and the irradiator over it.

* The anteroposterior, side-to-side, and vertical arms of the supporting structure (coordinate system) are calibrated in millimeters to facilitate accurate movement and positioning of the irradiator.

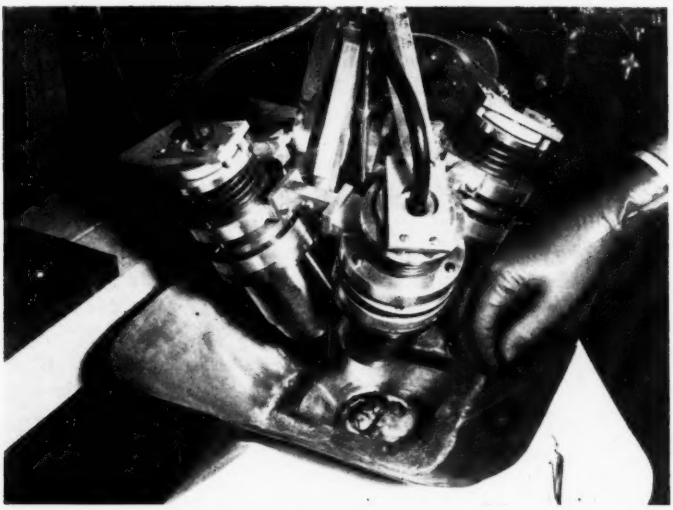

FIG. 2. Closeup view of multibeam irradiator, saline container and exposed brain of a monkey.

Previous to preparing the animal one determines the intensity at the focal spot of the irradiator by choosing a convenient voltage to electrically excite the crystals. An acoustic probe which makes possible relatively rapid determination of acoustic intensity has been especially developed for this purpose.[5] The exciting voltage corresponding to the desired sound intensity at the region of the lesion is then calculated. For a specific irradiation one adjusts: (1) the exciting voltage across the crystal, (2) the duration of the period of irradiation, and (3) the position of the coordinate system supporting the head to produce a lesion of the desired shape and size in the central nervous system. One lays down a rectangular pattern of the shape desired with shots 0.5 mm. between centers. Usually one-minute intervals were allowed between adjacent shots. The duration of each shot has been in the range from 0.5 sec. to 10.0 sec. for most of the work up to the present time.

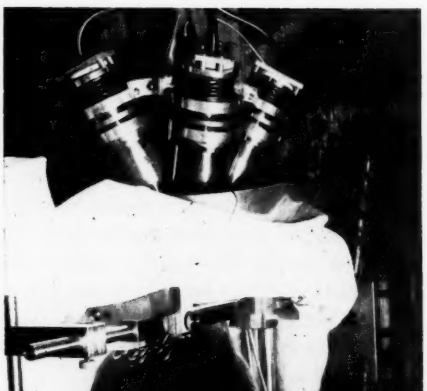

FIG. 3. General view of stereotaxic apparatus with animal and irradiator in position.

By employing the above techniques (sterility can be maintained throughout) and apparatus, accurately localized lesions have been produced within the depths of the mammalian brain by a focussed beam of ultrasound. Thirty-one cats were irradiated in the region of the internal capsule and thalamus in transverse planes from 9 to 11 mm. in front of the ears. The internal capsule of these cats is illustrated at a plane of irradiation in Fig. 4.

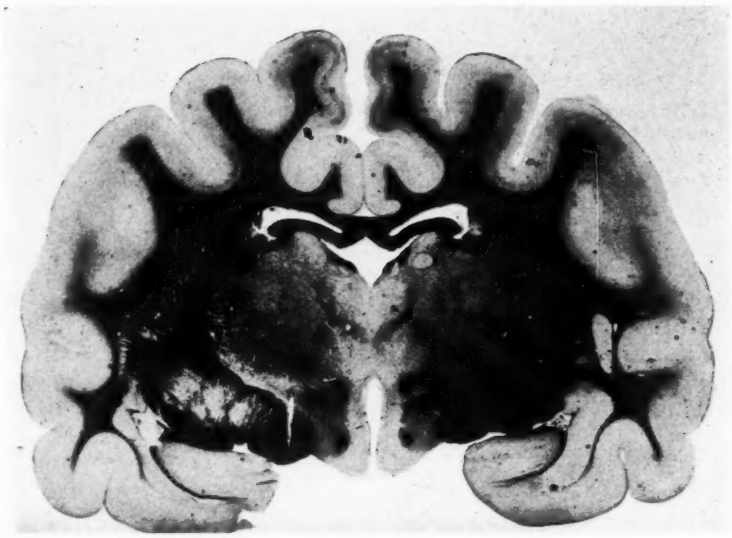

FIG. 4. Transverse section of brain of cat #101 in a plane of irradiation. Left internal capsule was irradiated at 210 watts/cm.^{2} for 4.0 seconds. Three days postoperative. Weil stain.

A series of animals were irradiated for 4.0 sec. at 210 watts/cm.^{2} with a rectangular array of shots, the array being 7.5 mm. laterally by 2 mm. longitudinally. The animals were observed after the irradiation for functional disturbances. Characteristic changes were produced in the placing reactions of the limbs. The cats were sacrificed at 1 day, 3 days, 12 days, and 30 days after irradiation to study the time course of the effects. They were perfused through the arterial system with formalin at the time of sacrifice and their brains were removed. Degeneration of the pathway from the motor cortex to the spinal cord was studied by Marchi preparations (Fig. 5). Tissue sections in the irradiated region were stained with thionin and Weil stains. The lesion is readily observed histologically in the cats that were sacrificed one day after irradiation. In fact, research currently in progress indicates that the changes produced in the tissue are evident two hours after exposure. At this dosage sound exerts no direct effect on blood vessels. The primary action of the sound is probably not a destructive effect upon the gross cell membrane but is a disturbance at a sub-microscopic level. At 3 days leucocytes begin to appear, indicating reaction to tissue damage. In the animals sacrificed at 12 days phagocytes are engaged in removing the debris in the dam-

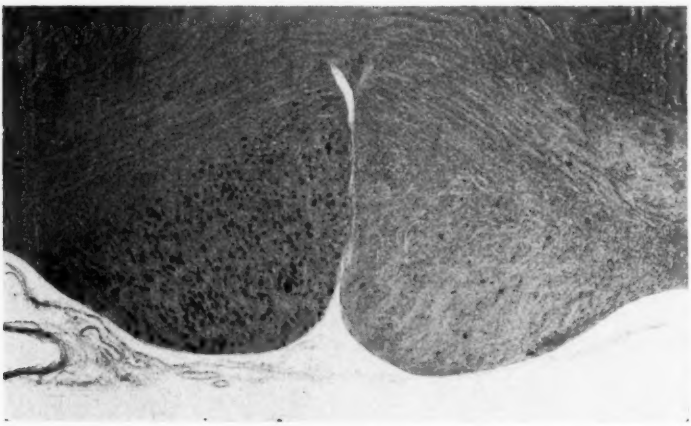

FIG. 5. Transverse section through pyramid of cat #76. Lesion illustrated in Fig. 6. Marchi stain.

aged area. At 30 days this process is continuing and scar-tissue formation has started (Figs. 6 and 7). At this dosage the nerve cell bodies of the thalamus seem relative immune to effects by the sound but the fibers of the internal capsule are irreversibly affected. It is to be emphasized that the sound beams entered the brain from directly above the superior and lateral

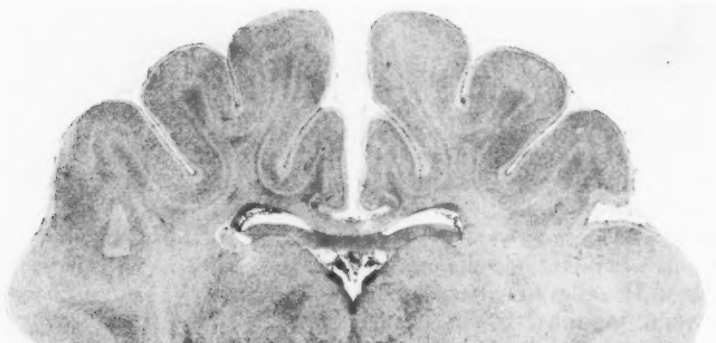

FIG. 6. Transverse section of brain of cat #76 in a plane of irradiation. Left internal capsule was irradiated at 210 watts/cm.^{2} for 4.0 seconds. Thirty days postoperative. Thionin stain.

aspects of the right frontal region to produce this lesion of the internal capsule and that the intervening brain tissue through which the sound beams passed has not been affected. There is no disruption of the blood-vessel walls—even in the site of the lesion.

An extensive investigation of the physical factors, including temperature and cavitation, possibly involved in the production of these effects of ultrasound on the central nervous system has been accomplished. The interested

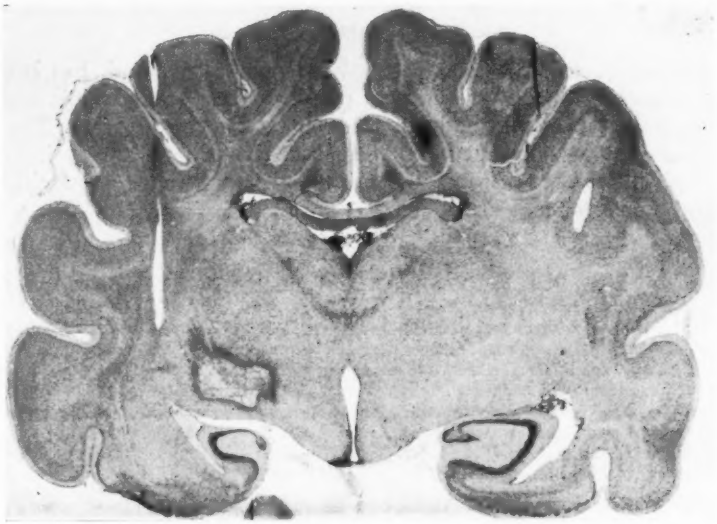

FIG. 7. Transverse section of brain of cat #80 in a plane of irradiation. Left internal capsule was irradiated at 180 watts/cm.^{2} for 7.0 seconds. Thirty-two days postoperative. Thionin stain.

reader is referred to previous publications concerned with this aspect of the problem.

Five years ago we initiated a study of the effects of ultrasound on the central nervous system. Three years have elapsed since the mammalian neurological studies were initiated and a neurosurgeon became closely associated with the group with the eventual objective of applying these techniques to human neurosurgery.[2]

Initially it appeared to us that, in the irradiating circumstances employed on mammals, ultrasound exerted a specific effect on nerve cells over the effect on nerve fibers and blood vessels. A subsequent numerical count of cell population in the irradiated areas failed to disclose any significant depopulation of cells. The most recent study (and the only study carried out with the multibeam irradiator) suggests a specificity for nerve fibers over nerve cells. Animal studies are in progress to determine the effect of ultrasound on cell bodies under various dosage conditions.

It has been apparent to us for some time that to realize the advantages

of the ultrasonic method (as contrasted with other methods) of producing localized lesions it is necessary to precisely locate the focal spot in the tissue and to know accurately the sound intensity. The procedure described in this paper makes feasible the severing of deep fiber bundles in the central nervous system in primates or man with the following advantages over other surgical techniques: (1) no disturbance to brain tissue except in the focal region, (2) no cutting of brain tissue, (3) no disturbance to the blood vessels, and (4) no opening of the dura mater.

SUMMARY

A technique, employing a focussed beam of ultrasound, has been described whereby accurately localized, quantitatively reproducible focal destructive lesions may be made in the central nervous system. The dura mater need not be opened and the nervous tissue need not be incised or perforated. There is no disruption of the blood-vessel walls—even within the site of the focal destructive lesion.

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A CLINICAL EXPERIENCE WITH MENINGIOMAS OF THE BRAIN*

FRANCIS C. GRANT, M.D.†
Philadelphia, Pennsylvania

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From January 1, 1931 to January 1, 1952, 1832 tumors have been verified on the neurosurgical service at the University and Postgraduate Hospitals of the University of Pennsylvania. In this group 219 were meningiomas, or 12 per cent. The purpose of the present report is to stress the problems involved in the surgical management of these tumors.

A meningioma is a benign tumor, which, if it can be completely extirpated together with its meningeal attachment, will not recur. Consequently, from the beginning, the operator has two ends in view: to remove the tumor completely and to remove it in such a fashion that the patient recovers and lives his life with a minimal neurologic deficit. This is the objective. Its attainment depends on a number of factors not under the surgeon's control: the size, and particularly the position, of the tumor and the neurologic deficit revealed by the patient prior to operation. And since these tumors grow so slowly, the clinical picture is no indication of the actual size of the tumor. These tumors are always much larger than the neurologic symptoms indicate.

Diagnosis and localization of a meningioma are not difficult. A careful history and neurologic examination, roentgen-ray films, ventriculography and arteriography will not only place the tumor correctly within the cranial cavity but will, in the majority of instances, determine the fact that the tumor is a meningioma. Arteriography should be avoided whenever possible. The information desired can be obtained just as satisfactorily and with less risk by ventriculography, except in an occasional subfrontal tumor. Following arteriography, the diodrast can diffuse out into the neck or produce a cerebrovascular spasm with disastrous results. Inasmuch as every patient harboring a tumor should have the ventricles tapped pre- and postoperatively for relief of pressure, ventriculography is the method of choice for the localization of silent lesions. In only 6 instances in this series was the tumor not exposed, and in 4 of these, the incision was correctly placed but the tumor lay too deep for identification.

Anesthesia is important. The modern anesthetist is all for endotracheal anesthesia. But in all cases of supratentorial lesions, local anesthesia, plus morphine, pentothal, or the barbiturates by vein if the patient becomes rest-

* Presented at the meeting of the Harvey Cushing Society, Hollywood, Florida, April 25, 1953.

† 3400 Spruce Street, Philadelphia 4, Pennsylvania.

less, is much safer. No matter how deftly an endotracheal tube is introduced, it remains in place for at least three hours. Edema of pharynx and larynx is sure to result with possible pulmonary complication three or four days later. In cases of subtentorial lesions, in which a clear airway is essential, an endotracheal tube is imperative. Space in the posterior fossa is at a premium even after relief of pressure by ventricular tap. Endotracheal anesthesia, while not entirely satisfactory, assures the operator that increased pressure from respiratory difficulties will be reduced to a minimum. Furthermore, postoperative tracheotomy has been done whenever necessary. This procedure has saved a number of desperately sick patients and is heartily recommended.

Whether the operation is carried out in the erect or the prone position depends on the facilities and the operator's training. The erect position, especially with subtentorial lesions, may afford better drainage of cerebrospinal fluid and more adequate exposure through smaller fields. But if a persistent drop in blood pressure necessitates a change in position, this may be difficult to accomplish without contamination of the wound. Furthermore, air emboli can occur with the patient erect.

We have had no large experience with the deliberate reduction in blood pressure by bleeding or by depressor drugs in the control of hemorrhage. Apparently, when a skilled and experienced anesthetist is available, this is a reasonably safe and very effective method to use in attacking the vascular and inaccessible subfrontal and subtentorial tumors.

This series of meningiomas has been divided arbitrarily into three groups: the tumors lying over the convexity of the brain along the longitudinal sinus; the tumors at the base of the skull about the olfactory groove, sphenoid or petrous ridges; and those lying subtentorially. The convexity tumors are the most numerous, produce striking symptoms of convulsions, hemiparesis, and sensory disturbances, and present the easiest surgical problem. Every effort should always be made to extirpate completely a tumor in this region. The basilar group are accompanied by relatively little neurologic evidence of their presence, for the most part mental changes, proptosis of one eye, a visual field deficit, or ocular muscle paresis. Local changes in the bone on roentgen-ray studies may be the only evidence of the presence of a subfrontal tumor. Therefore, since these patients are not seriously crippled by the lesion, the attempt at complete removal should not be carried to the point at which the patient suffers more from the surgeon's efforts to remove the tumor than he did from the tumor itself. The subtentorial tumors may give pressure, cranial nerve, and cerebellar symptoms rather promptly. A definite effort should be made to remove these lesions completely, especially if they do not involve the brain stem. The seventh and eighth nerves may be injured but the cerebellar symptoms disappear quickly if pressure is relieved, and remarkably little permanent damage is noted.

The surgical results that have been obtained in these three groups are shown in Tables 1, 2, 3, 4 and 5.

TABLE 1

334 Operations on 219 patients—41 deaths
Operative Mortality whole group—12.2%

Position	Number	Deaths	Case Mortality
Convexity	128	19	14%
Basilar	74	17	23%
Subtentorial	17	5	29%
Total	219	41	18%

TABLE 2

Convexity Group—128	19 Deaths	109 Survivors
Complete removals		95
Working	57	
Crippled	28	
Died intercurrent disease (6 working, 4 crippled)	10	(to 1-1-52)
Incomplete removals		14
Working	6	
Crippled	4	
Died recurrence (2 working, 2 crippled)	4	(to 1-1-52)

TABLE 3

Basilar Group—74	17 Deaths	57 Survivors
Complete removals		39
Working	21	
Crippled	9	
Died intercurrent disease (5 working, 4 crippled)	9	(to 1-1-52)
Incomplete removals		18
Working	5	
Crippled	2	
Died recurrence (3 working, 4 crippled)	7	(to 1-1-52)
Died intercurrent disease (2 working, 2 crippled)	4	(to 1-1-52)

A study of the postoperative fatalities in these cases brings into clear relief many of the problems involved. Fourteen patients (with 4 convexity, 8 basilar, and 2 subtentorial tumors) died of postoperative shock. By this term is meant a fatality within 24 hours, obviously caused by operative trauma alone, with deep stupor, a failure of pulse and blood pressure, a rise in respiratory rate, and hyperthermia. The fact that only 4 of the 19 deaths in the convexity tumor group were attributed to that cause, whereas 8 of the 17 basilar tumor fatalities and 2 of the 5 subtentorial fall into this category, is significant. Injury to the carotid vessels or hypothalamus in the basilar

TABLE 4

Subtentorial Group—17	5 Deaths	12 Survivors
Complete removals		8
Working	6	
Crippled	1	
Died intercurrent disease (crippled)	1	(to 1-1-52)
Incomplete removals		4
Working	2	
Died recurrence (crippled)	2	(to 1-1-52)

group and to the brain stem in the subtentorial group is a disastrous complication. Fatal postoperative shock following extirpation of a brain tumor is not caused by blood loss alone. Brain damage will produce it without severe bleeding. The judgment of the operator has always been at fault. The prevention of postoperative shock depends on two factors: first, the experience of the surgeon in knowing just how far he can carry the procedure with safety and second, an adequate supply of blood. And the presence of ample blood for transfusion is not always an unmixed blessing, for the surgeon may rely too much on replacement to cover his errors in judgment. An operator often attempts to remove a tumor in one stage and then, to his chagrin, discovers that an even greater than blood loss replacement will not rescue the patient. Exposure of the tumor brings up the critical decision: will the patient withstand the further operative trauma involved in the removal of a tumor of this size in this position? Should extirpation be attempted, the maneuver may well be accompanied by further blood loss and brain damage with consequent drop in pulse pressure and volume. The operator now finds himself with a tumor half in and half out of the wound and is compelled to complete the extirpation in order to close the wound. The consequent bleeding and brain damage may produce a state of shock, which often does not respond to transfusion, drugs, or any methods for relief. If any doubt exists, close the wound with proper supportive measures. (These tumors are benign and slow-growing. Nothing serious can happen to the patient if final removal of the lesion is postponed for a week or two.)

Adequate exposure will go far towards preventing brain damage. Meningiomas are always unexpectedly bulky. The higher mortality with subfrontal and subtentorial tumors is in great part because of their inaccessibil-

TABLE 5

219 Cases	41 Deaths	178 Survivors	
Complete removals working		84	
Incomplete removals working		20	
Total returned to work		104	58%

ity. When attacking a lesion in either of these positions, the surrounding structures, the carotid branches or the brain stem and the cranial nerves, are so important that every move should be made under direct vision whenever possible. Brain retraction during exposure and the trauma of tumor removal spell postoperative edema. Postoperative tap of the ventricle will help to relieve pressure but large bone flaps and an open dura mater are equally important.

Postoperative hemorrhage has not been a problem in this series. Two deaths occurred in which the bleeding might have been a factor, and in 3 other cases the wounds were reopened and a clot was evacuated with recovery. These operative fields bleed from four sources: the tumor bed, between bone and dura mater, the temporal muscle, and the concavity of the bone flap. Bleeding from the tumor bed may be controlled with clips, the bovie, muscle, or foam. But the dura mater at the edge of the flap should be stitched up to the pericranium and pulled tight against the under surface of the bone to control ooze from between bone and dura mater. The temporal muscle should be stripped off the outer surface of the flap until only the fascial attachment remains. This checks bleeding from the concavity of the flap and exposes the under surface of the muscle so that coagulation may be applied. Always relax the flap and watch this muscle surface for bleeding points before replacing the bone.

But a most common cause for postoperative hemorrhage is the replacement of the flap and closure of the wound with the blood pressure low. The blood pressure is then raised by transfusion. The wound should not be closed until the blood pressure has returned to the preoperative level. Unless the tumor bed is observed until this blood pressure rise has occurred, many small vessels, apparently controlled, will begin to ooze again as the pressure is increased. Compression of the jugular veins by the anesthetist should be performed. In this way, any vessel, which might bleed postoperatively, if the patient vomited or coughed, can be seen. By these maneuvers, postoperative hemorrhage can be practically eliminated. When these precautions have been taken if the patient's stupor increases or the neurologic deficit becomes more marked postoperatively, this is probably because of edema and not because of hemorrhage.

The convexity tumors are the most numerous, usually afford the most definite clinical evidence of their position, present fewer surgical problems, and yield the most satisfactory postoperative results. Removal of the convexity tumor requires a flap to expose the longitudinal sinus, for most of them lie close to it. Once adequate exposure of the tumor is obtained, the dura mater should be cut about the lateral edge of the lesion and all vessels reaching the surface of the tumor should be controlled. After a line of cleavage is found between dura mater and brain, careful and cautious finger dissection should be used to separate the lesion from the surrounding brain. The tip of the dissecting finger can feel the one or two large vessels running into the mass from below and these can readily be clipped or coagulated.

The main venous supply to the tumor runs between the lesion and the longitudinal sinus. Unless the tumor is attached to the falx as well as to the dura mater, tilt the tumor medially across the falx and control this bleeding from beneath, then separate the dural attachment of the tumor from the sinus, being careful not to injure the sinus. If the rolandic vein runs across the upper surface of the tumor, save it if possible. Only too frequently the tumor is attached to both the dura mater and the falx. With the bovie, cut the tumor from its attachment to the falx and remove the bulk of the mass. Needle the longitudinal sinus to determine whether or not it is patent. If it is patent, trim off and coagulate the tumor close to it, and leave the sinus alone. The patient will be far better off as far as his neurologic deficit is concerned if he faces a slow recurrence at some future date, than if he is promptly made hemi- or quadriplegic with his tumor totally removed. If and when, in the future, recurrence is obvious, a venogram can be done to determine the patency of the sinus. If it is occluded, complete removal of the tumor and its attachment to the falx and the sinus may safely be attempted.

The subfrontal tumors are handled in the same fashion. But in attacking a subfrontal tumor, remember that these lesions usually produce minor neurologic defects and grow very slowly. Curiously enough, those tumors accompanied by most obvious invasion of bone are much smaller in intracranial content than lesions accompanied by minimal bone change. If a tumor produces marked thickening of the orbital plate and sphenoid ridge with few or no severe neurologic deficits, no attempt should be made to extirpate it. In any event, if and when a surgical attack is contemplated on a subfrontal tumor, the surgeon must use every precaution to minimize the operative neurologic damage. Few patients are satisfied to be told that their tumor has been completely extirpated and that they can live their normal life span with a partial or complete hemiplegia, which was not their preoperative complaint.

The frontal meningiomas, especially those that arise from the olfactory groove, may be bilateral and extend under the falx to involve the opposite side. They arise close to the point where the internal carotid artery enters the cranium and consequently they are frequently involved with one of the major branches of this important vessel. To clip the right anterior cerebral artery is a relatively safe procedure that is not followed by prolonged or serious neurologic sequelae. But surgical occlusion of the left anterior cerebral artery, of either middle cerebral, or of course, of the main trunk of either internal carotid artery, leaves the patient hopelessly crippled. One or both optic nerves, or the chiasm, may be adherent to the base or sides of the tumor and should be carefully identified and avoided.

A wide exposure is of first importance in any attack on a meningioma springing from the olfactory groove or from either end of the sphenoid ridge. A coronal incision with bilateral frontal flaps is often advisable. In forming the anterior limb of the flap or flaps, care must be taken to avoid entering the frontal sinus. Reduction of pressure by ventricular tap is im-

perative. If a single flap is used, the median edge of the flap should be placed across the longitudinal sinus so that, after the dura mater is opened, easy access may be obtained to the veins running from the longitudinal sinus to the adjacent frontal lobe. If the tumor is preponderantly right-sided, the right frontal lobe may be sacrificed from a point just in front of the origin of the sylvian fissure to the midline. Necessity for frontal lobe amputation may be avoided if, after coagulation of the veins running from cortex to sinus, the lobe is retracted laterally and the falx cut along its attachment to the crista galli. This involves ligation of the longitudinal sinus well anteriorly, which is an easy and harmless maneuver. Once the falx is freed anteriorly, one or both frontal lobes may be retracted posteriorly much more easily. Elevation of the appropriate frontal lobe along the level of the sphenoid ridge is now indicated, unless the tumor appears on the surface elsewhere. The presence, position, and possible size of the tumor should be determined as accurately as possible. The right frontal lobe is sacrificed if necessary. The degree to which a tumor in this area lends itself to complete removal depends on the firmness and position of its dural attachment at the base of the skull in the anterior fossa or along the sphenoid ridge. If it rocks easily on its base when the dissecting finger is carefully passed about it, complete removal may be possible and should be attempted. Gutting the mass with the bovie instrument to reduce its size may be indicated, unless hemorrhage is too severe. If the tumor is firmly fixed to the dura mater on a broad base, complete extirpation will be impossible. Removal of the upper part of the lesion with the bovie instrument or, if it is sufficiently soft in consistency, with the sucker, is all that can be accomplished. Inasmuch as only partial resection is possible, radical maneuvers that might result in injury to the carotid or to the optic nerves should be avoided.

Should the surgical attack on a meningioma be a one-stage or a two-stage procedure? These are benign tumors that do not recur if completely removed. A one-stage operation is much more satisfactory whenever possible. And with careful hemostasis, plus ample blood transfusion, the patient's condition can usually be kept within safe levels. But if the operator or anesthetist becomes anxious, no unnecessary risks should be taken; the operation should be terminated and completed at a second stage.

A meningioma may have its dural attachment anywhere in the posterior fossa, although most commonly it is attached close to the lateral or occipital sinus or along the edge of the posterior lacerated foramen. The one assurance of successful operation in the posterior fossa is adequate exposure.

Bilateral ventricular taps are carried out for relief of pressure. A bilateral suboccipital craniectomy, done laterally on the side of the lesion to expose the first mastoid cells and uncover the lower edge of the lateral sinus, and below to include the removal of the rim of the foramen magnum and atlas, is always indicated. The outer half of the cerebellar hemisphere overlying the tumor should be sacrificed if occasion demands. The relationship of the tumor to the glossopharyngeal and vagus nerves and to the brain stem deter-

mines the possibility for complete removal. The lower pole of the tumor is exposed first and these nerves are freed, if adherent to it. If they are injured during operation, the immediate result may seem successful but because of interference with swallowing function, the patient will usually succumb to aspiration pneumonia within a week or ten days. Immediate postoperative passage of a Levin tube for feeding will help to prevent this pulmonary complication, as will a tracheotomy, but serious damage to these nerves should be avoided at all costs. These nerves cannot be preserved unless they are actually seen, and they cannot be seen unless the widest possible exposure is obtained. Once the ninth and tenth nerves have been gently and carefully dissected free from the lower pole of the tumor and protected with a cotton patty, the capsule of the tumor is opened and the mass is gutted with the bovie instrument or a sucker. When the size of the tumor has been reduced as much as possible by intracapsular removal, the overlying stump of the amputated cerebellar lobe is gently retracted medially and the capsule of the tumor is carefully freed from the adjacent brain stem. The inferior cerebellar artery may run across the lower pole and may require cauterization or a clip. At the upper pole, the inferior petrosal vein should be looked for and controlled before the capsule is drawn out from this region. The seventh and eighth nerves can rarely be preserved, if complete removal is to be accomplished. Especially is this true if the tumor arises from the dura mater at the internal auditory meatus, for cauterization of the dura mater in the meatus may be necessary to destroy all cell nests in this region. Damage to the trigeminal nerve at the upper pole of the tumor should be avoided. With both fifth and seventh nerves destroyed, closure of the eyelids of the ipsilateral eye will be necessary to prevent keratitis and ulceration.

Many of these benign tumors can and should be removed. But these lesions are not uncommon in elderly patients; they grow very slowly, and at times are unexpectedly much larger than the degree of neurologic involvement and intracranial pressure suggests. Partial removal of the tumor, plus wide decompression, produces satisfactory results when complete removal is impossible. However, partial removal, plus inadequate decompression, as when the unilateral approach is used, may result in serious consequences, which are often avoided with the bilateral procedure.

Four patients in this series died of meningitis, 3 in the pre-antibiotic period. Meningitis is always a hazard in brain tumor surgery, because of the length of time the wound is exposed.

Postoperative treatment consists in ventricular tap, routinely every 8 hours, until the fluid is clear and the flap is flat. Unless the blood pressure is low, the head of the bed is raised about 20 degrees. Bone flaps are dressed at the end of 48 hours and the drain and sutures are removed. The suboccipital wounds are taped over the head for support of the neck and a hole is left in the dressing for ventricular tap. They are not redressed for one week. Fluid is given by mouth and vein as required. A Levin tube is frequently

used in cerebellar cases for feeding, and to keep the stomach empty to prevent vomiting.

An attack on a meningioma varies in difficulty and the chances for complete removal of the tumor with the size and position of the lesion. The basilar tumors, whether above or below the tentorium, are less easily extirpated than similar lesions on the convexity. A subtotal removal without aggravation of existing neurologic deficit will be more satisfactory to the patient and to his family than a complete removal and the assurance of a long life, severely crippled.

VASCULAR MALFORMATIONS IN THE REGION OF THE GREAT VEIN OF GALEN

LYLE A. FRENCH, M.D., AND WILLIAM T. PEYTON, M.D.
Division of Neurosurgery, Department of Surgery, University of Minnesota Medical School, Minneapolis, Minnesota

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THIS report concerns arteriovenous malformations in the region of the pineal gland. The 5 cases reported here and similar cases reported in the literature have several factors in common. All are of congenital origin, are arteriovenous shunts with venous drainage into the great vein of Galen, and appeared to be amenable to surgery. They often are associated with hydrocephalus. In 2 of the 5 cases the communication was between the anterior cerebral artery group and the great vein of Galen, in 2 it was between the posterior cerebral artery group of vessels and the great vein of Galen, and in 1 it was between the superior cerebellar artery and the great vein of Galen. In each of the cases the diagnosis was established by angiography. When therapy was instituted it was ligation of the vessels on the arterial side and in these instances postoperative angiography revealed failure of filling of the vascular malformations.

The first report found in the literature of arteriovenous malformations leading into the great vein of Galen was by Jaeger, Forbes and Dandy[7] in 1937. They described a communication between the circle of Willis and the great vein of Galen in a 4-year-old child whose symptoms began at approximately the age of 8 months. The child had an internal hydrocephalus. This they attributed to the greatly dilated great vein of Galen pressing on the aqueduct. Because the patient had no history of trauma, they concluded the aneurysm was congenital.

In 1940 Russell and Nevin[11] reported 2 cases in children. In one the aneurysm was a complex sacculated structure communicating between the left posterior cerebral artery and the great vein of Galen. There was an associated absence of the sigmoid portions of both lateral sinuses. In their second case the arteries coming over the corpus callosum connected with the great vein of Galen. In both cases there was an internal hydrocephalus.

In 1945 Alpers and Forster[1] reported on an 18-year-old boy with bilateral hydrocephalus secondary to a calcified arteriovenous malformation in the pineal region. The arterial supply came through the posterior cerebral or the choroidal arteries and the venous drainage was through the great vein of Galen. Alpers and Forster doubted that involvement of the great cerebral vein is capable of producing internal hydrocephalus. They mentioned the investigations of Bedford[3,4] indicating that occlusion of this vein in the dog is incapable of producing internal hydrocephalus despite scattered re-

ports to the contrary. They believed that the hydrocephalus more probably was caused by pressure and occlusion of the aqueduct of Sylvius.

In 1947 Oscherwitz and Davidoff[10] reported on a 27-year-old woman with a calcified aneurysm situated in the midline between the occipital lobes. The arterial supply was from the branches of the circle of Willis and the venous drainage was into the great vein of Galen. There was no hydrocephalus.

In 1949 Boldrey and Miller[5] reported 2 cases of arteriovenous fistulas connecting the arteries of the circle of Willis and the great cerebral vein of Galen. They treated their first patient with ligation of the external and internal carotid arteries in the neck and considered this therapy of distinct value. It is difficult to understand how this would improve the patient unless the temporary diminution of blood going through the fistula would permit some thrombosis within the lesion. However, no mention was made of such thrombosis.

Olivecrona and Riives[9] in 1948 reported on various types of arteriovenous aneurysm of the brain, but it could not, from their report, be ascertained if any of them were between the anterior or posterior cerebral arteries and the great vein of Galen.

Gillingham[6] in 1953 reported 1 patient with an arteriovenous malformation between the cerebral vessels and the great vein of Galen. He emphasized that unless vertebral angiography is carried out as a routine in addition to carotid angiography, in the more posteriorly placed malformations the feeding vessels from the posterior cerebral artery often are not demonstrated. He also stated that it is helpful to perform vertebral angiography with simultaneous carotid compression on the same side as the lesion. By this maneuver, minor implications of the posterior cerebral artery can be more easily demonstrated. Carotid compression, he stated, having robbed the malformation of its principal supply from the middle cerebral artery permits filling of the lesion from the posterior cerebral flow.

Also in 1953 Askenasy, Herzberger, and Wijsenbeek[2] reported on the association of hydrocephalus with vascular malformations of the brain. The purpose of their report was to emphasize the fact that hydrocephalus may be caused by congenital malformation coincident with the cerebral vascular abnormality, or by recurrent small hemorrhages occurring in the subarachnoid space with the production of an adhesive leptomeningitis and subsequent closure of the subarachnoid spaces, or by a faulty distribution of blood and subsequent oxygenation of the brain. Lemmen and Schneider[8] emphasized that obstructive hydrocephalus may occur secondary to vascular abnormalities in the third ventricle.

EMBRYOLOGY

The internal carotid artery appears first at approximately the 3 mm. stage of the embryo. At 4 mm. two divisions are apparent. The anterior division gives rise to the anterior and middle cerebral and the anterior choroi-

dal arteries. The posterior division develops into the posterior communicating artery and later gives rise to the posterior cerebral artery together with its posterior choroidal branch.

The middle cerebral artery has in 16–18 mm. embryos become a prominent stem with several branches spreading over the cerebral hemisphere. At about the same time the anterior communicating artery becomes a definite vessel. The anterior cerebral arteries then extend up between the cerebral hemispheres. A small median anterior cerebral artery arises from the anterior communicating artery. This vessel persists normally in many vertebrates and anomalously in man as a single anterior cerebral artery (median artery of the corpus callosum). When it does, there is often an associated lack of normal development of the paired anterior cerebral arteries. Arteriovenous abnormalities may arise between terminal branches of the normal anterior cerebral arteries or the anomalous median artery of the corpus callosum or the middle cerebral artery and the venous branches draining into the great vein of Galen.

The definitive posterior cerebral artery at an early stage cannot be identified unequivocally, but its adult stem of origin is represented early and is usually the most distal end of the original posterior communicating artery. There are many other small branches arising at the same site. These are, of course, small branches of the posterior cerebral artery in the adult and as is the case with the formation of the anterior cerebral artery a collateral branch finally overshadows the primary artery. The progressive enlargement of the posterior cerebral artery is probably a function of the progressive enlargement of the posterior portion of the cerebral hemisphere.

The posterior choroidal artery is the more anteroventral of two large branches supplying the diencephalon; the other courses toward the pineal primordium. Two equally conspicuous branches emerge to supply the mesencephalon. Very early in the development, these future anterior choroidal and the future posterior choroidal arteries are definite vessels and are directed toward and eventually terminate in the choroidal infolding at the diencephalic roof.

Many of the vessels extending into the mesencephalon and diencephalon anastomose across the midline with their counterparts on the opposite side. Vestiges of these anastomoses between the primitive vascular channels crossing the midline may result in the formation of arteriovenous aneurysms. Persistent and enlarged communications with the venous outflow via the great vein of Galen may produce malformations comparable to those presented in this report.

CASE REPORTS

Case 1. A boy at the age of 2 months was observed to eat and sleep poorly, to be extremely irritable and to have an enlarged head. He was seen at that time in the dermatology clinic because of an atopic dermatitis. At the age of 15 months he was admitted to the University hospital because of pneumonia and malnutrition. His head circumference was 50 cm. Three months later he was readmitted because of

malnutrition. His head circumference was 51 cm. At the age of 21 months he was readmitted because of malnutrition and vomiting.

Examination. At this time a pneumoencephalogram revealed enlargement of the lateral ventricles with a slight shift of the entire ventricular system to the left. There was evidence of a large mass near the midline in the right parieto-occipital region.

1st Operation. Right occipito-parietal craniotomy was performed on Sept. 15, 1949. A white shining mass was encountered in the posterior part of the parietal lobe at a depth of 6 cm. A No. 22 needle was introduced into the mass and arterial blood was obtained. It was felt then that the lesion was an arteriovenous aneurysm. The hemorrhage was controlled and the wound was closed.

Postoperatively bilateral carotid angiography was performed (Figs. 1 and 2). The right middle cerebral artery was elevated. The right posterior communicating

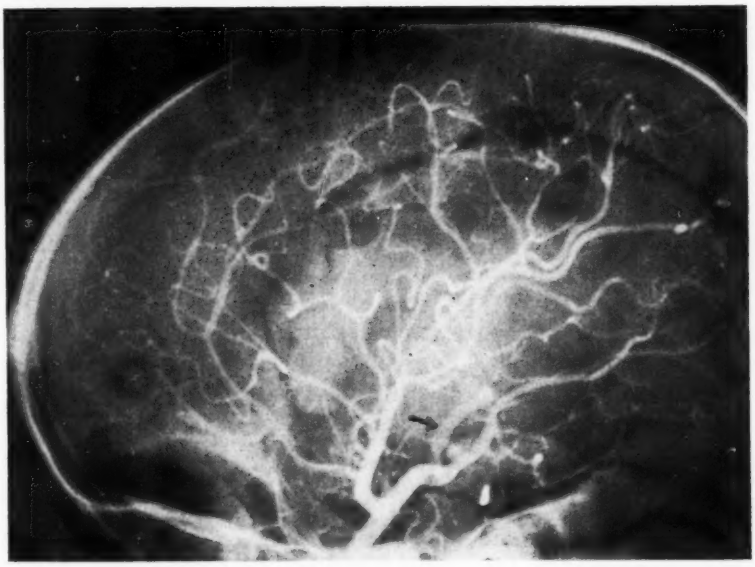

FIG. 1. *Case 1.* Left carotid angiogram. The enlarged posterior communicating artery as well as the abnormally large vessel (arrow) leading into the aneurysm can be seen. The aneurysm itself does not fill in this exposure.

artery and its continuation, the posterior cerebral artery, were much larger than normal and arising from the latter was an enlarged tortuous vessel which entered an aneurysmal-like cavity measuring approximately 5 cm. in diameter. It was felt that the displacement of the middle cerebral artery was caused by this large aneurysmal sac. The left carotid angiogram revealed similar findings, that is, an enlarged posterior cerebral artery with a large tortuous branch extending into the aneurysm. The aneurysm was in the region of the pineal gland and could be seen to drain into the great vein of Galen.

2nd Operation. A right temporoparietal craniotomy was performed and the large tortuous vessel arising from the posterior cerebral artery was clipped with silver clips.

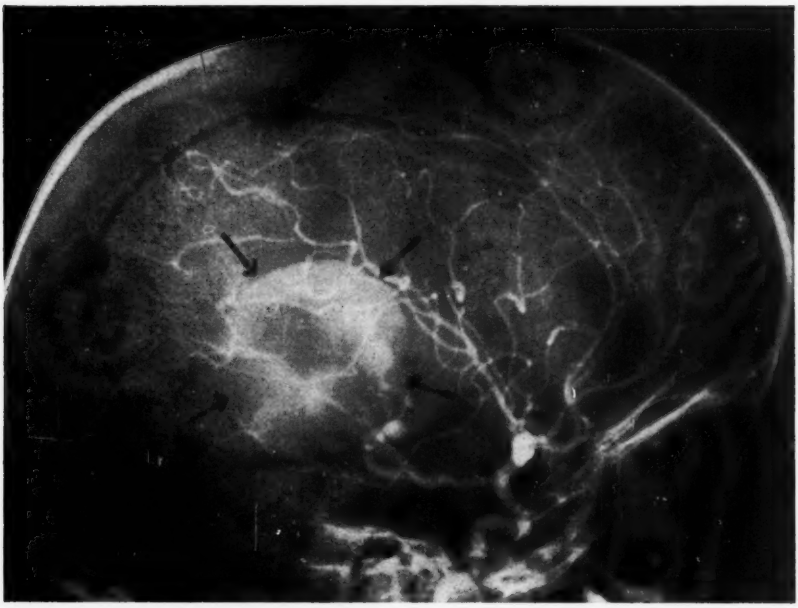

FIG. 2. *Case 1.* Right carotid angiogram. Arrows point to arteriovenous aneurysm in region of pineal gland.

3rd Operation. Two weeks later, through a left parietotemporal craniotomy flap, the large vessel entering the aneurysm on this side was clipped.

Course. He was discharged from the hospital on Jan. 4, 1950.

On Aug. 7, 1950 he was readmitted for general evaluation of an apparent mental retardation. He was almost 3 years old. He was described as being a well developed, well nourished child with a head circumference of 52 cm. and a weight of 10.6 kg. Neurological examination revealed no abnormality. He ate well and played but could not sit alone nor hold his head up. X-rays revealed that the clip on the left side had slipped off the vessel and although he was very much improved in general appearance it was felt that the artery was still feeding the aneurysm.

4th Operation. The left craniotomy was reopened and the area of the vessel exposed. A white fibrous band about 1 to 1½ mm. in diameter was found. It was felt that this was the artery previously clipped. Apparently it had become occluded and thrombosed before the clip slipped off. In any event, another clip was put on the structure and the wound was closed.

Course. The patient tolerated the procedure well. Subsequently he has been seen on many occasions in the clinic. Examination on May 1, 1953, at which time he was 5½ years of age, revealed that he was 37 inches tall and weighed 28½ lbs. His head circumference was 53 cm. and his mental age was evaluated to be approximately 8 months.

Case 2. A 12-year-old boy in 1950 began to play truant from school. Because of this he repeated the seventh and eighth grades. His mother stated that he became

less reliable and in 1951 a farm placement was made but was terminated after the patient became restless, began to steal, set fires, and became homesick.

During October, 1952 he had the first of two spontaneous subarachnoid hemorrhages. Right carotid angiography (Figs. 3 and 4) demonstrated an arteriovenous malformation on the medial aspect of the right cerebral hemisphere just above and posterior to the location of the great vein of Galen. The abnormal mass of vessels occupied an area 3 cm. in diameter. Contrast media appeared to traverse very rapidly from the malformation into the straight sinus and into the great vein of Galen.

FIG. 3. *Case 2.* Right carotid angiogram. Arteriovenous malformation is visible in region of great vein of Galen. Contributing vessels arise from branches of anterior cerebral arteries.

This arteriovenous malformation filled equally well in angiography performed via the left carotid artery. It was felt at that time that the malformation was inoperable, so the patient was discharged from the hospital.

On July 23, 1953 he was readmitted because of persistent headaches and personality aberration. It was decided to attempt to occlude the vessels entering the angioma.

Operation. On Aug. 29, 1953 a craniotomy was performed exposing the parietal region on both sides of the midline. A spinal puncture was performed to reduce the dural tension. The intracranial pressure remained elevated so that hexamethonium was given to reduce the systolic blood pressure to about 80 mm. of mercury. One large vein extending from the cortex to the superior sagittal sinus was sectioned in order to expose down along the left side of the falx. The region of the corpus callosum was visualized. An abnormally large artery, approximately $2\frac{1}{2}$ mm. in diameter, was seen to the right of the midline and lying on the corpus callosum. It was felt that this was the principal artery contributing blood to the vascular malformation. The vessel was clipped with two silver clips. The wound was then closed in the usual manner.

FIG. 4. *Case 2.* Anteroposterior carotid angiogram showing arteriovenous malformation draining into great vein of Galen.

Course. Eleven days after operation left carotid angiography was again performed. The anterior cerebral artery filled proximal to the site at which it was clipped but there was no filling of the angioma. He was discharged from the hospital on Sept. 10, 1953.

He has been seen three times in followup clinic, the last time on Mar. 10, 1954. He had no headaches and otherwise had been doing well physically, in behavior, and in school adjustment.

Case 3. A 22-year-old lady had been symptom free until July 27, 1953, when there was sudden onset of severe generalized headaches. Shortly thereafter her speech became slurred, she had difficulty standing, and she became comatose.

Spinal puncture revealed grossly bloody spinal fluid. Physical and neurological examination revealed no abnormalities except nuchal rigidity and a positive left Babinski sign.

Bilateral carotid and left vertebral angiograms were performed (Figs. 5 and 6). An arteriovenous malformation, 1½ cm. in diameter and located to the right of the midline just above the corpus callosum in the region of the pineal gland, was visualized. It seemed to arise from a branch of the pericallosal artery. There was very rapid filling of the great vein of Galen from the aneurysm. The lesion filled well after injection of either the carotid or the left vertebral artery. In the right carotid angiogram the anterior cerebral artery seemed to be quite small but the lesion also filled from this side. The left anterior cerebral vessel seemed to be very large and tortuous and it was felt that this was the primary vessel feeding into the malformation.

FIG. 5. *Case 3.* Carotid angiogram revealing arteriovenous malformation in region of great vein of Galen. Entering vessels are entirely from anterior cerebral group.

Operation. On Aug. 25, 1953, a craniotomy exposing the parietal region bilaterally was performed. An opening in the dura mater was made to the left of the sagittal sinus. One large cortical vein was sacrificed in order to expose down along the falx. The corpus cal-

losum was visualized and along its upper surface was an unusually large tortuous artery which was felt to be the left anterior cerebral vessel. It was clipped with several clips.

Postoperatively a repeat angiogram revealed filling of the arteriovenous malformation but to a lesser extent than preoperatively. It appeared that the surgical clips placed on the anterior cerebral artery had simply reduced the blood supply to the arteriovenous malformation. She was discharged from the hospital on Sept. 2, 1953.

She returned for followup examination on Mar. 16, 1954. She had been entirely free of symptoms and neurological examination revealed no abnormality.

FIG. 6. *Case 3.* Vertebral angiogram showing arteriovenous malformation in region of great vein of Galen draining into straight sinus.

Case 4. A 14-year-old girl on July 1, 1953 had onset of severe left-sided headaches. She immediately became uncooperative and talked nonsense. She vomited four times. She was put to bed and after 1½ hrs. she went to sleep and could not be aroused. Three hours later she regained consciousness. Spinal puncture revealed bloody spinal fluid. A stiff neck developed and the headache persisted for approximately 3 weeks.

Examination on Oct. 30, 1953 at the Mayo Clinic revealed no abnormality. On Nov. 6, 1953 bilateral carotid and right vertebral angiography was performed (Figs. 7 and 8). This revealed a vascular malformation approximately 2 cm. in diameter. The entering vessels were branches of the posterior cerebral arteries and the drainage was into a dilated great vein of Galen.

Because of lack of symptoms and seemingly normal neurological findings surgical therapy was deemed inadvisable at this time.

Case 5. A 43-year-old man in 1943 began having severe headaches, profuse sweating, photophobia, and lethargy.

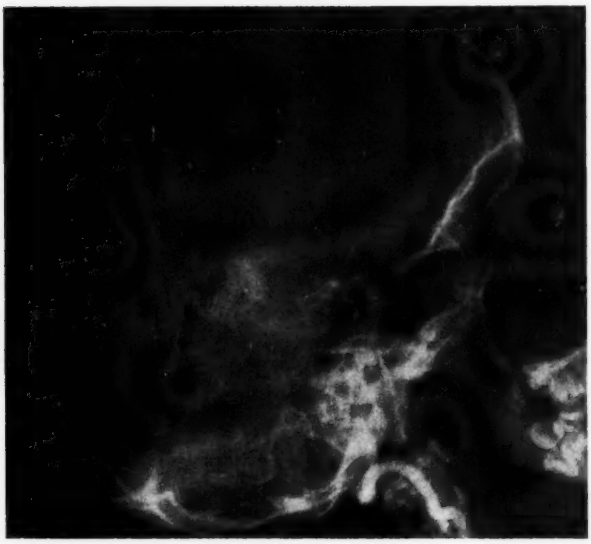

FIG. 7. *Case 4.* Vertebral angiogram showing arteriovenous malformation in region of great vein of Galen filling from branches from posterior cerebral artery.

FIG. 8. *Case 4.* Anteroposterior projection of vertebral angiogram revealing malformation in region of great vein of Galen.

In 1950 severe headache occurred with development of nuchal rigidity and unconsciousness. Carotid angiograms revealed no abnormality. He recovered from the hemorrhage but had a depressive mental reaction with paranoid trends.

In 1951 a second episode of subarachnoid hemorrhage occurred. Vertebral angiograms revealed a very dilated superior cerebellar artery leading into a large aneurysmal sac. This sac was in the region of the pineal gland. The venous drainage was via a dilated great vein of Galen.

Operation. A posterior fossa exploration revealed the vascular abnormality but the dilated superior cerebellar artery could not be safely visualized and ligated through this approach.

Course. It was planned to reoperate at a later date via a supratentorial approach but the patient refused surgery. Because of his psychosis he was committed to an institution.

DISCUSSION

It is felt that these vascular malformations, which are very unfavorable for removal because of their location, nevertheless are operable when it is possible to demonstrate their arterial supply. This may not be ideal treatment but it is reasonable to think that it will prevent recurrent hemorrhages and possibly relieve other symptoms by causing thrombosis in the lesion or decreasing its size if not thrombosed. Only by long followup study or postmortem examination can this be determined.

Concerning diagnosis, there seems to be no absolute sign nor symptom indicative of these lesions in the region of the pineal gland. As reported in the literature, it is entirely possible for them to be evidenced by a very chronically increased intracranial pressure with slowly developing hydrocephalus. This is demonstrated in Case 1. However, the other patients, interestingly enough, were older individuals who presented symptoms of spontaneous subarachnoid hemorrhage, and in 2 there was a prelude of personality changes. The latter could be attributed to increased intracranial pressure but there was no evidence of this on spinal puncture nor was there evidence of hydrocephalus in the angiograms.

It is believed that these malformations present a pathologic entity because of the apparent congenital origin from abnormal communications between the anterior or middle cerebral arteries and the venous drainage into the great vein of Galen. Perhaps they are even a clinical entity when occurring at a young age.

CONCLUSIONS

A series of 5 cases* of arteriovenous malformations located in the midline in the region of the pineal gland is presented. Provided one can discern on angiographic studies the vessels leading into the malformation, it is possible to make a direct operative attack on the entering vessel, thereby obliterating or at least diminishing the size of the malformation.

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* Case 4 was used through the kind permission of Dr. Collin S. MacCarty, Mayo Clinic, Rochester, Minnesota. It was included because it so well represented a variation in this general group of malformations.

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RESULTS OF DECOMPRESSION OPERATION FOR TRIGEMINAL NEURALGIA*

J. GRAFTON LOVE, M.D., AND HENDRIK J. SVIEN, M.D.
Section of Neurologic Surgery, Mayo Clinic and Mayo Foundation,† Rochester, Minnesota

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TAARNHØJ[3] introduced a new operation for the treatment of trigeminal neuralgia in 1952. His procedure consisted of intradural decompression of the gasserian ganglion and posterior root of the fifth cranial nerve. In this operation the posterior root is not sectioned, and consequently sensation in the face is not sacrificed. Love,[1] in 1952, modified Taarnhøj's operation and carried out an extradural approach to the gasserian ganglion and posterior root of the fifth cranial nerve.

During the period from June, 1952 to March, 1954, we and our associates have treated 100 patients with trigeminal neuralgia by decompression of the gasserian ganglion and posterior root of the fifth cranial nerve. The procedure employed in each of these cases is the modification of Taarnhøj's procedure devised by Love,[2] which may be described briefly as follows.

PROCEDURE

Through a small subtemporal craniectomy opening the middle meningeal artery is ligated and divided. The dura mater is stripped from the foramen ovale upward and backward to expose the intracranial portion of the third branch of the trigeminal nerve, the gasserian ganglion and the dura propria over the adjacent portion of the posterior root of this ganglion. The dura mater underneath the temporal lobe is then incised posteriorly, parallel to the posterior root of the ganglion, and the tentorium overlying the posterior root in the posterior fossa is also incised. By this technic the posterior root of the gasserian ganglion is thoroughly decompressed.

POSTOPERATIVE COMPLICATIONS

From Table 1 it is evident that the procedure of decompression as employed in this series is a safe one. The 1 death occurred in a patient who had, from all clinical signs, recovered from the operation. Only in 1 case did palsy of the third cranial nerve result, and in this instance the palsy was slight and cleared up completely in a month. There were no instances of palsy of the fourth cranial nerve. Bleeding from the superior petrosal sinus has not been a problem; it is usually controlled easily by the application of absorbable gelatin sponge (gelfoam). In only a few instances has clipping of the sinus been necessary.

* Read at the meeting of the Harvey Cushing Society, Santa Fe, New Mexico, May 6, 1954.
† The Mayo Foundation is a part of the Graduate School of the University of Minnesota.

TABLE 1

Decompression operation for trigeminal neuralgia: complications in 100 cases

	Cases	Comment
Deaths	1	Coronary disease, 9 days after operation
Facial palsy	16	9 very slight
Third-nerve palsy	1	Slight, transient
Fourth-nerve palsy	0	
Herpes	25	
Sensory impairment	27	Subjective only in 13
Complete relief immediately	51	

The incidence of facial-nerve palsy and of herpes has been somewhat higher after this procedure than after section of the posterior root. This results from the fact that in the decompression operation the dura mater must be reflected more extensively from the gasserian ganglion and the posterior root than is necessary when section of the posterior root is performed.

Postoperative subjective sensory impairment occurred in 13 patients. These sensations, consisting of paresthesias and dysesthesias, generally disappeared within 2 weeks, but in an occasional case persisted for several months. In the main, these subjective sensations have not been troublesome symptoms.

Sensory loss occurred in some degree in 14 patients. In most of these instances, the loss was of minor degree and occurred in small isolated islands. In only 1 case was the sensory loss profound. In this case the degree of sensory loss was graded 3 (on a basis of 1 to 4) and involved the major portion of the area supplied by the second and third divisions of the trigeminal nerve. Sensation returned to practically normal in 5 months. So far as we know, there was no instance of keratitis in this series.

Complete relief of the trigeminal neuralgia was immediate in 51 patients. The remaining 49 patients had "tic-like" pain of varying degrees of severity during some period of their hospital stay (usually 5 to 8 days). In 4 instances this pain was so severe that either posterior-root section or alcohol block was carried out during the hospital stay. In the remaining cases the pain was less severe and no definitive treatment was carried out during the hospital stay.

In the majority of cases in which tic-like pain complicated the hospital stay, the pain was described as being something like the "old" pain, but not nearly as severe. Although it occasionally came on shortly after the patient had aroused from anesthesia, usually it occurred on the third or fourth day after operation and persisted for 3 to 4 days. Then pain was not constant, but came in "showers" several times a day. In a few instances, it could be triggered by touching some portion of the face, usually the nasolabial fold. In a few cases, the pain recurred from time to time after the patient had been dismissed. The relationship of this pain to the eventual result will be discussed below.

RESULTS

In an attempt to evaluate the results of this procedure, a questionnaire was sent to all patients who had not been examined within the last 6 weeks. The data obtained are included in Table 2.

TABLE 2

Decompression operation for trigeminal neuralgia: results

Months after Operation	Cases	Result		
		Relief	Recurrence	Indeterminate
19–22	16	6	9	1
13–18	17	5	10	2
7–12	41	26	10	5
1–6	26	21	2	3
Total	100	58	31	11

The patients listed as relieved stated rather unequivocally that they had not experienced further pain and were well pleased with the result of operation. The patients listed as having recurrences either had had further definitive treatment (posterior-root section or alcohol block) or had experienced tic-like pain which bothered them to the extent that they were dissatisfied with the result. Some of these patients did not have severe recurrent pain, but had definite disturbances which, we feel, vitiated the results of operation. A somewhat typical reply from this group of patients is given in the following reproduction.

1. Since your return home following your operation have you had any tic pain? *Yes.* If so, when did it start? *Two Months ago.* Has it persisted? *Yes, probably 100 or more very mild, single pains daily. None of the previous severe, chain-type pains.*

2. Have you had any further medical or surgical treatment for your tic pain since your operation? *No.* If so, please describe briefly, giving type and date of treatment. *If pains persist, I may try to make appointment with you for checkup this summer.*

Four patients in this group who had recurrence did not have typical trigeminal neuralgia but had atypical facial pain.

Distribution of cases according to interval between time of operation and time of recurrence of the pain is shown in Fig. 1. It is evident that in approximately half of the failures, the pain recurred within the first month after operation. In only 3 cases did pain recur after 1 year of relief. The import of the graph is somewhat distorted by the fact that 4 patients listed as failures had atypical facial pain and were not relieved by the decompression operation. Another factor which is partially responsible for the large number of recurrences in the first month after operation is that early in our experience with this operation we reoperated, in the first few days after the original procedure, on 4 patients who experienced tic-like pain described above.

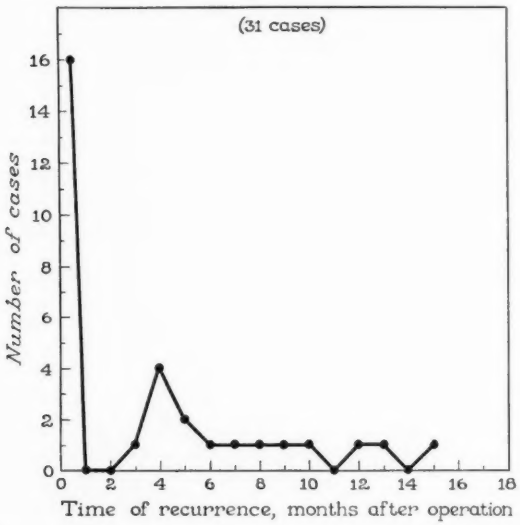

FIG. 1. Distribution of cases according to interval between time of operation and time of recurrence of pain.

From what we have learned of the significance of this pain, we do not now reoperate as early as we did in these 4 cases.

Of the 31 patients who experienced recurrent pain, 12 have sought further definitive care. For one reason or other, the remaining 19 patients have carried on with their recurrent pain (Table 3).

TABLE 3

Decompression operation for trigeminal neuralgia: disposition of patients with recurrence

	Cases
Posterior-root section	8
Alcohol injection	4
No further surgical treatment	19
Total	31

The patients listed as having indeterminate results (Table 2) have been a difficult group to categorize. These patients had not written to us complaining of a poor result, but when they received the questionnaire they reported having some disturbance, generally vague and transient. A rather typical answer from this group of patients is given in the following reproduction.

1. Since your return home following your operation have you had any tic pain? *Yes.* If so, when did it start? *Oct. 30.* Has it persisted? *No—I had it 1 day, pain side of my nose into forehead.*

2. Have you had any further medical or surgical treatment for your tic pain

since your operation? *No.* If so, please describe briefly, giving type and date of treatment. *Feb. 13 I had another attack pain side of my nose and into forehead just 1 day. Dr. Love suggested B_{12} shots. However, pain left me and I did not have any vitamin B_{12} injections. I have had no pain in my jaw.*

It is possible that some of these patients will eventually have true recurrences.

In order to determine the relationship of the occurrence of tic-like pain in the early postoperative period, discussed above, to the eventual result, we reviewed the cases in which more than 12 months had elapsed since operation (Table 4). It would seem that such pain generally, but not always, augurs a poor result.

TABLE 4

Relationship of tic-like pain in the early postoperative period to the result observed 12 to 22 months after operation

Pain 12 to 22 Months after Operation	Patients		
	Total	Pain in Early Postoperative Period	
		Absent	Present
Relief	11	8	3
Recurrence	19	6	13
Total	30	14	16

A similar study of relationship of postoperative sensory disturbance to the eventual result indicated that the presence of sensory loss is not necessarily associated with continued relief of pain (Table 5).

TABLE 5

Relationship of sensory disturbance in the early postoperative period to the result observed 12 to 22 months after operation

Pain 12 to 22 Months after Operation	Patients		
	Total	Sensory Disturbance in Early Postoperative Period	
		Absent	Present
Relief	11	7	4
Recurrence	19	13	6
Total	30	20	10

SUMMARY

The results of decompression of the gasserian ganglion and posterior root of the fifth cranial nerve for trigeminal neuralgia in 100 consecutive cases

have been reviewed. The incidence of relief of pain by this procedure is less than when the posterior root is sectioned; however, preservation of sensation in the face, eye and tongue may be worth the chance one takes in failing to obtain relief of pain by this nonmutilating procedure.

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CASE REPORTS AND TECHNICAL NOTES

ACOUSTIC NEUROMAS IN CHILDREN

REPORT OF 2 CASES

WINCHELL McK. CRAIG, M.D., HENRY W. DODGE, JR., M.D.,
AND PAUL J. ROSS, M.D.

Section of Neurologic Surgery, Mayo Clinic, and Mayo Foundation, Rochester, Minnesota*

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Tumors affecting the acoustic (eighth cranial) nerve occur most frequently in the fourth, fifth and sixth decades of life, according to statistics reported in the majority of published series.[2,4,9] Recently, we operated on 2 children, 11 and 14 years of age, who had typical acoustic neurofibromas (neurilemmomas). The uncommon occurrence of typical tumors of the eighth nerve in the cerebellopontine angle of children less than 15 years old has prompted us to report these cases.

The available pertinent literature lends emphasis to the fact that these tumors are rare in children. In his monograph *Tumors of the Nervus Acusticus*, Cushing[2] in 1917 quoted Henschen as reporting on a patient 19 years old with a tumor of the eighth nerve. Cushing,[3] in 1927, again reported on a patient between the ages of 10 and 15 years. The exact age was not given. Zülch[10] reviewed 121 histologically verified brain tumors in a series of patients 1 to 20 years old, in 1938. There was 1 case of a neurofibroma of the cerebellopontine angle in this series. Of the 100 tumors in children reported by Bailey and his collaborators[1] in 1939, 1 case concerned a neurinoma (neurofibroma) of the twelfth cranial nerve in a patient 12 years old. There was no instance of such a tumor affecting the eighth nerve. Of the 130 patients with acoustic tumors reviewed by Nielsen[9] in 1942, the youngest was 18 years old. The youngest patient in the series (154) reviewed by Gonzalez Revilla[5] in 1947 was 19 years old. Keith, Craig and Kernohan[6] reported 427 brain tumors in children less than 15 years old in 1949. There was no instance of a neurofibroma of the acoustic nerve in this report. Love[7] in 1950 reported on an intrapetrous neurofibroma that had originated in the eighth cranial nerve in a 16-year-old female. This patient's symptoms were of 8 years' duration, and presumably the tumor had been present when she was 8 years old. Edwards and Paterson[4] listed 2 patients between 10 and 20 years of age, but exact ages were not stated. An unusual case in which a unilateral tumor of the eighth nerve afflicted an $8\frac{1}{2}$-year-old child was reported by Mark and Sweet[8] in 1952. This lesion was an acoustic neurofibroma. The patient was 6 years old at the time of onset of symptoms. Among the patients with approximately 410 verified unilateral acoustic neurofibromas operated on at the Mayo Clinic between January, 1915 and July, 1953, only 2 have been less than 15 years old.

The cardinal signs and symptoms of tumors of the acoustic nerve in the cerebellopontine angle are so well known that it seems unnecessary to repeat them here.

* The Mayo Foundation is a part of the Graduate School of the University of Minnesota.

However, it occurred to us that presentation of two cases of these tumors in children would be of interest and would show the close similarity between the symptoms as they appear in young children and the symptoms as they appear in adult persons.

REPORT OF CASES

Case 1.—A white boy 11 years old was examined at the Mayo Clinic because of bifrontal headaches that had begun 8 months earlier. The headaches usually had been present when the patient awakened in the morning, and by noon had subsided. The headaches had been constantly present throughout the patient's illness, and were aggravated by coughing, sneezing and straining. Considerable relief was obtained by lying down. Two episodes of nausea and vomiting had been associated with the headache.

Concurrent with the headaches, the patient became aware of an intermittent buzzing in his left ear associated with a gradual loss of hearing. Periodic attacks of "dizziness," during which the patient would stagger and bump into objects, also were experienced.

One month before examination the patient's left arm tired easily and had become increasingly awkward.

Neurologic Examination. Positive findings were sensory impairment on the left side of the face with decreased corneal reflex, slight weakness of the left facial muscles and minimal inco-ordination of the upper extremity and the presence of Babinski's reflex on the left. Movements of eyes disclosed horizontal nystagmus, more marked to the left, with paresis of conjugate gaze to the left. Subacute edema of the ocular fundi (right 2 D., left 3 D.) was noted. Caloric stimulation was difficult to evaluate because of the marked spontaneous nystagmus.

A diagnosis of tumor of the left cerebellopontine angle was made.

Operation. Left suboccipital craniectomy was performed. After the dura mater had been opened, the cerebellum was retracted mesially. An acoustic neurofibroma, 8 by 5 cm., was found. Total removal was accomplished. After removal of the tumor the seventh cranial nerve appeared to be intact, and the dura mater was closed. The internal auditory meatus was not curetted.

Course. The patient's postoperative convalescence was uneventful. A postoperative peripheral type of palsy of the seventh cranial nerve developed on the left. The patient was dismissed on the 12th postoperative day.

Four months later the patient returned for re-examination. He was found to have made an excellent recovery, except for the persistent deafness. The facial palsy on the left showed some abatement to clinical examination and to electromyographic tracings.

Case 2.—A 14-year-old girl was first seen at the clinic in September, 1952. She complained mainly of loss of hearing in the left ear of 5 years' duration, buzzing in the left ear for the same period, and twitching of the left eyelid of 2 years' duration. Generalized headaches had been present for the year previous to her admission, associated with episodes of nausea and vomiting which had become more frequent in the last 6 months. Three weeks prior to admission she had become aware of a loss of balance, difficulty in walking and inco-ordination of the left arm. She also had noticed some degree of double vision.

Neurologic examination revealed horizontal nystagmus, more marked on gazing to the left, loss of hearing on the left graded −3 (0 normal; −4 complete deafness) and a decreased corneal sensation left (graded −3).

In addition, hyporeflexia on the left, drooping of the left side of the face, marked inco-ordination of the left upper and lower extremities, ataxia and muscular hypotonicity on the left side were recorded.

There was also swelling of the optic nerve heads (right 4 D., left 5 D.). The electroencephalogram was reported as disclosing no abnormality. Roentgenograms of the skull showed slight erosion of the tip of the petrous ridge on the left, and decalcification of the floor of the sella (Fig. 1).

In view of the clinical and radiologic findings, a diagnosis of tumor of the left cerebellopontine angle was made.

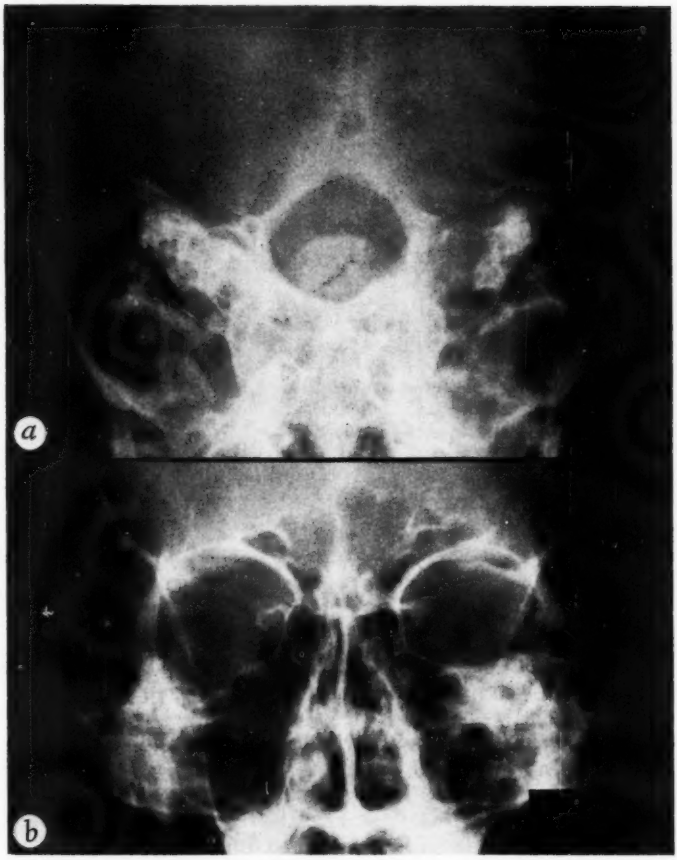

FIG. 1. *Case 2.* (*a*) Roentgenogram made with the patient in the Towne position, to illustrate erosion of the left petrous ridge by a neurofibroma (neurilemmoma) of the left eighth cranial nerve in the cerebellopontine angle; (*b*) anteroposterior roentgenogram.

Operation. Left suboccipital craniectomy was performed. A typical acoustic neurofibroma was encountered occupying the entire right cerebellopontine angle. In view of the patient's condition and the extent of the tumor a subtotal removal of the tumor was carried out. This seemed to be in the best interest of the patient under the existing conditions at the time of operation.

Course. The postoperative recovery was uneventful. Examination at the time of dismissal revealed marked abatement of neurologic symptoms and the papilledema was subsiding.

COMMENT

It is apparent that acoustic neurofibromas are uncommon in children less than 15 years of age. Two cases in which acoustic neurofibromas afflicted children 11 and 14 years of age have been presented. The similarity of the clinical course of these tumors in children and adults is evident in these cases.

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SPINOTHALAMIC TRACTOTOMY FOR INTRACTABLE ITCHING

C. W. Taylor, M.D.*

Division of Neurosurgery, Calgary General Hospital, Calgary, Alberta, Canada

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Will high section of the pain tract abolish intractable itching? In the light of our experience with one case we would say that the answer is "no."

Faced with this problem, I talked it over with Dr. K. G. McKenzie, who suggested consideration of a high pain tract section.[1] It was decided to try the operation on one side. If it proved helpful the second side could be done at a later date. It was argued that pain tract section abolished tickle sensation as well as the sensations of heat and cold and so might give a better result than a lobotomy. The result in our patient here has been a complete failure. Postoperatively the tickle element of light touch was indeed gone, but the patient continued to itch and excoriation continued relentlessly. The case is briefly recorded as it may be helpful to others faced with a similar but unusual neurosurgical problem.

CASE REPORT

Mr. A.M., aged 71, had suffered from a chronic erythematous skin eruption for many years. Itching had become intractable so that incessant scratching excoriated the skin over both arms and legs. Subacute infection was frequently superadded so that repeated hospitalizations had been necessary. As soon as he was discharged from hospital excoriation would again occur. He denied any other somatic complaints. There was no suggestion that he was psychotic. Because the situation was desperate, a neurosurgical opinion was sought.

Operation. While awaiting a bed in the Calgary General Hospital he had a severe attack of herpes zoster involving the 2nd, 3rd and 4th sacral dermatomes on the left side, and he complained of severe pain in his left loin. For this reason we decided to cut the right spinothalamic tract. This was done 5 mm. below the obex by means of an incision 4 mm. deep, placed between the rootlets of origin of the spinal accessory and hypoglossal nerves.

* 410 Greyhound Bldg., Calgary, Alberta.

Course. Immediately postoperatively his postherpetic pain was relieved and he had complete analgesia below the 2nd rib on the left side. Between this level and the lower border of the mandible anteriorly and the superior nuchal line posteriorly, there was some very patchy appreciation of a pin point as "a little sharp." He denied that there was any change in his itching.

Examined 3 months later, he still had complete analgesia below the level of the 2nd rib. Loss of appreciation of temperature was present below a level 3 cm. above the clavicle anteriorly, and the 3rd cervical spinous process posteriorly. Between the 2nd rib and jaw-nuchal line level (including the entire left arm) pin prick was present in a patchy distribution and less sharp than on the sound side. Above this level it was normal.

Light touch was unimpaired on the left side on testing with contact only (cotton wool). Below the jaw-nuchal line level, the "tickle" element of light stroking with cotton wool was completely absent. On the sound side the sole of the foot was extremely sensitive so that the plantar response was difficult to evaluate. On the left side one could scratch the sole of the foot without discomfort. He described the sensation in the right sole as "ticklish," in the left sole as "ordinary touch."

There was now slight hyperactivity of the tendon jerks in the left lower limb. The abdominal reflexes were sluggish on the left side, and the plantar response, although downgoing on both sides, was less briskly so on the left side. The right heel-knee test manifested a mild cerebellar type of inco-ordination and his gait was a little unsteady.

If anything, more excoriation of the skin was present on the left side than on the sound side. The only difference in the itching was that it was no longer on the surface. It seemed "deeper in," which is perhaps why he now scratches harder on this side. His herpetic neuralgic pain has not recurred.

SUMMARY

A case of intractable itching is presented in which the "tickle" element of light touch was abolished by spinothalamic tractotomy in the medulla but the patient continued to itch.

My thanks to Dr. A. S. Gelfand, whose patient this is, for his kind permission to record the case, and to Dr. K. G. McKenzie for his helpful criticism.

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A TECHNIC FOR ANASTOMOSIS OF THE FACIAL NERVE AND SPINAL ACCESSORY NERVE

Hendrik J. Svien, M.D., and Andrew L. Karavitis, M.D.
Section of Neurologic Surgery, Mayo Clinic, and Mayo Foundation, Rochester, Minnesota*

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The facial nerve emerges from the stylomastoid foramen, which lies medial to the mastoid process. Inasmuch as the sternocleidomastoid muscle has its origin from the mastoid process, this muscle covers the area of emergence of the facial nerve

* The Mayo Foundation is a part of the Graduate School of the University of Minnesota.

from the stylomastoid foramen (Fig. 1a). We have found that, on occasion, it is difficult to find the facial nerve as it emerges from its foramen.

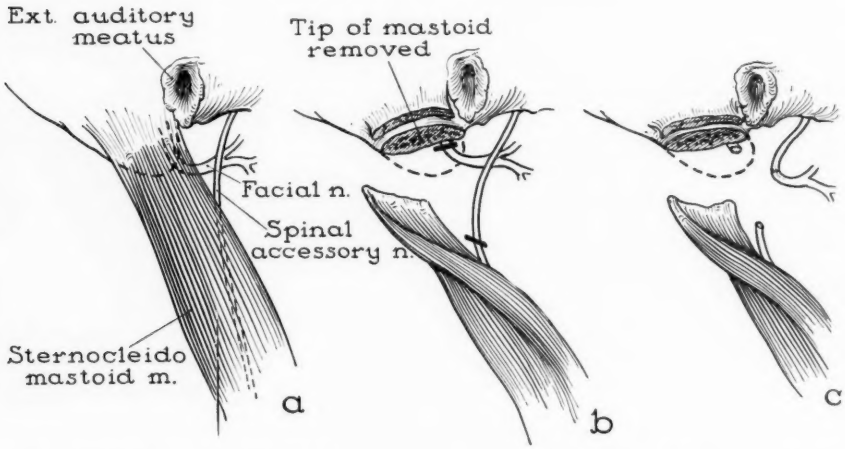

FIG. 1. (a) Relationship of the facial nerve, as it emerges from the stylomastoid foramen, to the tip of the mastoid process and to the sternocleidomastoid process. (b) Sternocleidomastoid muscle has been sectioned and the lower third part of the mastoid process has been removed. (c) Proximal end of the spinal accessory nerve has been sutured to the peripheral end of the facial nerve.

To expose the facial nerve more easily at its foramen, we have recently employed the following technic.

TECHNIC

The incision in the skin is carried back over the lower third part of the mastoid process to expose the origin of the sternocleidomastoid muscle. The short, tendinous origin of this muscle is sectioned, so that a cuff of tissue remains for resuture of the tendinous origin. The lower third part of the mastoid process is then freed of the attachment of the muscle, so that the tip of the mastoid is well exposed. With a rongeur, the lower third part of the mastoid process is removed (Fig. 1b). If mastoid air cells are entered, they are plugged with bone wax. When the lower third part of the mastoid process has been removed, the stylomastoid foramen is easily identified and the facial nerve is picked up as it emerges from this orifice. The facial nerve is sectioned close to the stylomastoid foramen (Fig. 1c) and the anastomosis to the proximal stump of the sectioned spinal accessory nerve is completed in the usual manner. After completion of the anastomosis, the previously divided origin of the sternocleidomastoid muscle is resutured.

COMMENT

We have employed this technic in the last 7 cases of total removal of acoustic neurinomas in which the facial nerve was sacrificed intracranially. We have found that it has greatly facilitated location of the facial nerve. Mastoid air cells were entered, but no complications have followed such an action.

GLOSSOPHARYNGEAL NEURALGIA ACCOMPANIED BY UNCONSCIOUSNESS*

JAMES L. THOMSON, M.D.†
Norfolk, Virginia

(Received for publication June 21, 1954)

The purpose of this presentation is to discuss the diagnostic criteria of glossopharyngeal neuralgia and to emphasize the role of the syndrome that resembles that of the carotid sinus reflex, as seen in an occasional case.

The syndrome of glossopharyngeal neuralgia was first described by Weisenburg[10] in 1910 in a case of angle tumor pressing on the 9th cranial nerve. Ten years later Sicard and Robineau[8] reported 3 cases of glossopharyngeal neuralgia. During the following 7 years until 1927, 2 cases had been reported by Harris,[3] 9 from the Mayo Clinic, and 2 by Dandy.[2] Adson[1] in 1924 presented a technique for peripheral nerve section in the neck for this nerve. He said that it was a difficult surgical procedure because of the anatomical position of the nerve. At the time he had explored the possibility of cutting the nerve intracranially, by cadaver dissection, illustrating the unilateral cerebellar approach. However in 1927 Dandy reported the first intracranial section of the nerve, when he operated upon 2 patients within 6 weeks' time through a unilateral cerebellar craniectomy wound. Since then there have been many case reports illustrating the diagnostic and operative features of the disease.

Glossopharyngeal neuralgia differs from trigeminal neuralgia (tic douloureux) only in the location of the pain. Both have characteristic locations of the sudden, severe, paroxysmal, lightning-like pain, frequently set off by external stimuli. Each generally occurs in middle to late life. It remains only to distinguish the location of the pain by taking a careful history to establish the correct diagnosis. However, occasionally the patient is unable to give an exact account of the pain either because of its severity or because of mental deficits, such as senility, low mentality, etc. As we all know, this pain is located in the glossopharyngeal region, back of the tongue or in the ear. Confusion in diagnosis should occur only when the most severe pain is located in front of the ear or seemingly within it. Then the differential diagnosis of neuralgia of the nervus intermedius (nerve of Wrisberg), or 3rd division tic must be made. Cocainization of the throat usually, but not always, abolishes the pain for some minutes and thus aids the diagnosis.

Intracranial section of the 9th nerve alone generally relieves the pain entirely but if the ear pain is especially bad, section of the upper two filaments of the vagus should be done, which has been stressed by both Dandy and Spurling.[9]

The resultant anesthesia is confined to the pharynx, nasopharynx, back of the tongue and tonsillar pillars. No motor deficit has been shown resulting from the paralyzed stylopharyngeus muscle.

A much less frequent involvement in the disease process is the resemblance to the syndrome of the hyperirritable carotid sinus. The carotid sinus receives its nerve supply from branches of the glossopharyngeal (nerve of Hering—an afferent branch),

* Read at the annual meeting of the Southern Neurosurgical Society, Baltimore, Maryland, January 29, 1954.

† 405 Wainwright Bldg., Norfolk 10, Virginia.

vagus and sympathetic nerves. The nerve of Hering has been shown to be the depressor nerve from the sinus and the vagal branches respond to chemical stimuli, such as atropinization. Weiss[11] and associates worked out the carotid sinus syncope syndrome, describing three types: (1) vagal type, in which syncope results from cerebral anoxia caused by reflex cardiac asystole; (2) depressor type, in which syncope results from fall in blood pressure alone; and (3) cerebral type, in which syncope occurs without change in cardiac rate or blood pressure. When the neuralgic pain is unusually severe, bradycardia to asystole, hypotension, syncope and convulsive movements may occur. This group of symptoms resembling those of the carotid sinus reflex is mediated through the afferent glossopharyngeal branches in the throat rather than from within the sinus (nerve of Hering).

Following this work of Weiss, reports of intracranial section of the 9th nerve for hyperirritable carotid sinus reflex have appeared and the results are quite satisfactory.

Syncope and cardiac arrest associated with glossopharyngeal neuralgia were first referred to by Riley and associates[6] in 1942, but no operation was performed. In 1948 Ray and Stewart[4] reported a similar case and referred to another of Browder's which had been seen but not reported. Ray's patient was completely relieved by intracranial section of the 9th nerve.

In 1950 Roulhac and Levy[7] were the first to note convulsive seizures associated with glossopharyngeal neuralgia. The patient was a 72-year-old white woman with a 20-month history of typical pain in the left side of her throat. Three weeks previous to admission, she began having convulsive movements shortly after the onset of a paroxysm of throat pain. There was twitching of the mouth, with clonic movements of the arms and upward deviation of the eyes. These would last only a few seconds. She was put on Phenobarbital and Dilantin, and improved to such a degree that the carotid sinus reflex element of the neuralgia was almost missed. She was discharged and 10 days later was readmitted, having many more paroxysms of pain with an increased number of convulsions. Then an electrocardiogram was done demonstrating asystole. The left glossopharyngeal and upper two filaments of the vagus nerve were sectioned intracranially with prompt and complete relief of the pain and convulsions. Roulhac and Levy believed that the syncope and convulsions occurred from afferent stimuli arising in the glossopharyngeal nerve rather than the carotid sinus, the mechanism being bradycardia with a fall in systemic blood pressure and cerebral anoxemia (Weiss—vagal group classification).

Richburg and Kern[5] in 1953 reported a similar case. The patient was a Texas farmer, who had severe throat pain with frequent attacks of asystole, syncope and convulsions. The sinus syndrome was relieved by administration of atropine. Intracranial section of the 9th nerve and upper two filaments of the vagus nerve gave permanent relief of the entire syndrome.

The present report concerns another case of glossopharyngeal neuralgia associated with convulsions but without asystole or fall in blood pressure, which was initially mistaken for tic douloureux of the 3rd division of the left 5th cranial nerve. Temporal preganglionic subtotal sensory neurectomy was done without relief. The true nature of the pain was later recognized, and the 9th nerve was cut intracranially with prompt relief of all symptoms.

CASE REPORT

Case #11914-52. A 67-year-old colored woman was referred stating that for 3 months she had had intermittent, excruciating pain in the left side of the face. It would sometimes appear

by talking, eating, coughing, or drinking cold water. It seemed to be intense in front of the ear and involve the lower portion of the cheek and jaw. There was a second-degree burn on the left cheek from using heat. Also she had lost a great deal of weight, being afraid to eat because of fear of onset of pain. No further history could be obtained from the patient on repeated questioning and this was fragmentary, as the attacks of pain were so close together and she cooperated very poorly. When attempting to talk she would stop quickly, having a severe paroxysm of pain lasting 10 to 30 seconds. At one time she would point to the angle of the jaw, and again would hold the chin region. At other times she complained of the ear hurting. Similarly stroking the jaw region would give the impression of producing a pain, but the paroxysms were so frequent that it was uncertain that a trigger zone existed. The tonsillar and posterior tongue regions were stimulated without positive information.

Examination. The patient was of average size. B.P. was 130/88. On the left cheek at the angle of the jaw was a burn, 3 cm. in diameter, which was healing. The nasopharynx and ears showed no pathology. Both lung fields were clear and no enlargement of the heart was found. The heart rate and sounds were normal. Abdominal and pelvic examinations were negative. Neurological findings were normal excepting for the appearance of severe pain.

The blood showed 11.4 gm. of hb., 6,100 WBC, sedimentation rate of 24, negative Wassermann, fasting blood sugar of 125 mg. per cent, N.P.N. of 27, and alkaline phosphatase of 1.7 units. Urine was normal. Roentgenograms of skull, cervical spine and temporomandibular joint were normal.

1st Operation. Temporal preganglionic sensory neurectomy of the lower two thirds of the left 5th cranial nerve was done under intratracheal anesthesia 3 days after admission.

Course. When the patient had reacted well from the anesthesia she complained of the same pain and exhibited the same type of behavior toward it. During the next 3 days the paroxysms were more frequent, and severe. She now refused to eat because of precipitating an attack.

On the 4th postoperative day, while observing an attack of very severe pain, vision suddenly became fixed, her head dropped forward, and unconsciousness ensued with strong tonic-clonic movements of the head, upper extremities and, to lesser degree, of the legs. These movements lasted 10 to 15 seconds, stopped, and she quickly regained consciousness being momentarily free of pain and well oriented. During several similar episodes of unconsciousness the pulse remained strong with the rate not being reduced more than 20 beats per minute (not less than 60 per minute), and the blood pressure remained above 120/70. The nasopharynx was cocainized thoroughly but the paroxysms of pain would continue with and without external stimulation.

A nose and throat consultation was obtained but examination failed to demonstrate nasopharyngeal pathology or a trigger zone in the pharyngeal region. A diagnostic pneumoencephalogram was done 7 days postoperatively and appeared normal.

2nd Operation. Five days later the left glossopharyngeal and upper two filaments of the vagus nerve were sectioned under intratracheal anesthesia through a unilateral cerebellar craniectomy approach.

Course. On awakening from this procedure she was free of pain and no further convulsive movements occurred. B.P. remained at the preoperative level of 130/80, convalescence was satisfactory, and she was discharged symptom-free 8 days later. When last seen the following month, she had had no return of the pain.

COMMENT

This case is unusual in that there was no appreciable change in heart rate or blood pressure during the carotid sinus syndrome period of the pain. It would correspond to the cerebral type of Weiss. Pressure on each carotid sinus before and after operation had no effect on the carotid sinus reflex syndrome. Certainly this woman's pain reflex was mediated in the throat, and by excessive stimuli through the afferent glossopharyngeal nerve caused the convulsive phenomenon, similar to that which would be initiated through a hyperirritable carotid sinus.

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A CLAMP FOR TEMPORARILY OCCLUDING SMALL BLOOD VESSELS

Samuel P. W. Black, M.D., and William J. German, M.D.
Department of Surgery, Yale University School of Medicine, New Haven, Connecticut

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A small, light, and effective artery clamp may be adapted from an inexpensive electrical test clip* (Fig. 1). Historically, this type of artery clamp, a small spring forceps also known as a "bulldog" or "serre fine," dates from about the middle of the nineteenth century and has changed but little in form since that time.[1] It was not until the advent of aseptic surgery at a somewhat later date, however, that it became possible to occlude a blood vessel temporarily while a procedure was performed upon it with routine success in re-establishing its continuity and patency.[3,4] Concomitant with this achievement the artery clamp, of which the spring forceps is but one type, came to assume its present importance. There are now many forms of artery clamps available commercially, and DiPalma[2] has devised a method of making a small artery clip from a safety pin.

The clamp presented herein is made of phosphor-bronze and weighs 2 gm. It takes a high polish and may easily be filed free of sharp edges. The instrument is small enough to be applied to a blood vessel by means of a silver-clip applicator, which, when placed on the "catch," allows the operator to position the clamp about the vessel with accuracy and relative ease before allowing it to close (Fig. 2). It can occlude any artery caught completely between its jaws, which are smooth enough to be applied directly to the vessel if so desired. Should too strong a pressure be exerted the spring can be forced together; or, if the jaws exert too weak a pressure, this may be altered by forcibly separating the spring. Removal of the small screw at one end of the clamp allows the position of the instrument to be controlled by means of a thread placed through the opening thus made.

* Termed "Wee-Pee-Wee" clip by the manufacturers, The Mueller Electric Company, Cleveland, Ohio.

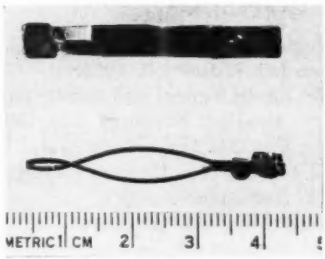

FIG. 1

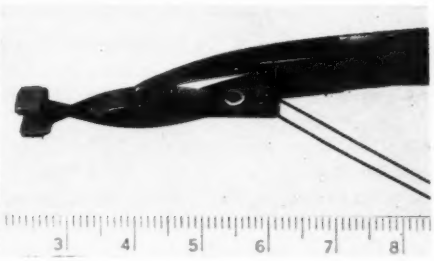

FIG. 2

This clamp has been found to have a definite clinical and laboratory usefulness. It has been employed to occlude temporarily the anterior cerebral artery and the middle cerebral artery of man during aneurysmorrhaphy. For that purpose the jaws are rubber-shod and their grip upon the artery is relaxed at appropriate intervals without unseating the instrument from its position in the wound. In the experimental laboratory it can occlude the femoral or carotid artery of an animal as large as a dog weighing 15 kg. In general it effectively serves the many functions of a "bulldog" within the limitations of its size and weight.

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NOTICES

CONGRESS OF NEUROLOGICAL SURGEONS

The next meeting of the Congress of Neurological Surgeons will be held at the Waldorf Astoria Hotel in New York City, November 4, 5 and 6, 1954.

Dr. Kenneth McKenzie of Toronto will be the honored guest and deliver papers titled "Brain Tumor with Special Reference to Acoustic Neuroma and Benign Gliomas"; "Experiences with Sympathectomy for Vascular Hypertension and Leukotomy for Mental Disturbance"; and "Spasmotic Torticolis, Ménière's Syndrome and Results Following Tractotomy for Trigeminal Neuralgia."

Symposiums on Cervical Trauma by Dr. Frank Mayfield, Cincinnati, and Dr. Howard Rusk, New York City, will be followed by a panel discussion with Dr. Thomas Hoen, Dr. K. G. McKenzie, Dr Francis Grant, Dr. J. Lawrence Pool, Dr. I. M. Tarlov, Dr. Bronson Ray, Dr. John E. Scarff, Dr. L. M. Davidoff, Dr. Lester Mount, Dr. Jefferson Browder, and Dr. C. G. de Gutiérrez-Mahoney.

A panel discussion on the Medicolegal Aspects of Head Injuries will be moderated by Dr. A. Earl Walker of Johns Hopkins University and will include Dr. William Caveness, Dean Roscoe L. Barrow of the University of Cincinnati College of Law, and Mr. W. Scott Allan of the Liberty Mutual Insurance Company.

MONTREAL NEUROLOGICAL INSTITUTE

The Montreal Neurological Institute of McGill University has announced the following staff reorganization:

Dr. Theodore Rasmussen, recently Professor of Neurological Surgery at the University of Chicago, has joined the staff as Neurosurgeon and Professor of Neurology and Neurosurgery to undertake supervision of teaching and research.

Dr. Wilder Penfield continues as Director of the Institute and Chairman of the Department of Neurology and Neurosurgery in the Faculty of Medicine of McGill University.

The Institute laboratories will continue to be directed as follows: Dr. William Cone, Surgical Neuropathology; Dr. K. A. C. Elliott, Neurochemistry; Dr. Herbert Jasper, Neurophysiology; Drs. Francis McNaughton and George Olszewski, Neuroanatomy and Medical Neuropathology.

Direction of the clinical departments is as follows: Dr. William Cone, Neurosurgeon-in-Chief and Professor of Neurosurgery; Dr. Francis McNaughton, Neurologist-in-Chief and Associate Professor of Neurology; Dr. Arthur Elvidge, Associate Neurosurgeon and Assistant Professor of Neurosurgery; Dr. Preston Robb, Assistant Director (Hospitalization) and Assistant Professor of Neurology; Dr. Herbert Jasper, Electroencephalographer and Professor of Experimental Neurology; Dr. Donald McRae, Neuroradiologist and Assistant Professor of Neurological Radiology.

The Laboratory for Research in Multiple Sclerosis, started by Dr. Roy Swank, will be continued under the direction of Dr. J. B. R. Cosgrove.

NEUROSURGICAL SOCIETY OF AMERICA

The 7th annual meeting of the Neurosurgical Society of America was held at Grand Hotel, Mackinac Island, Michigan, July 21–24, 1954.

The officers elected are as follows: President, Everett F. Hurteau; Vice-President, Collin S. MacCarty; Vice-President, George Ehni; Secretary, Lester A. Mount; and Treasurer, I. Joshua Speigel.

The next meeting will be held at Del Monte Lodge, Pebble Beach, California, March 16–19, 1955. The meeting is intended for the members and invited guests.

SPINAL CORD INJURIES

A REVIEW OF THE EARLY TREATMENT IN 300 CONSECUTIVE CASES DURING THE KOREAN CONFLICT

MAJOR GORDON T. WANNAMAKER, M.C., U.S.A.*

Section of Neurological Surgery, Tokyo Army Hospital, Tokyo, Japan

(Received for publication June 17, 1954)

THIS report is based on the early phases of treatment of 300 consecutive patients with spinal injuries at the Tokyo Army Hospital from September 1950 to May 1952.† Of these patients 254 were United Nations battle casualties from Korea with penetrating wounds of or about the vertebral column with neurological involvement (Table 1). The remaining 46 had closed injuries similar to those encountered in civilian localities (Table 1). All statistics herein presented were compiled in Tokyo and include a few casualties from Korea that were not treated at mobile neurosurgical units as well as some casualties from accidents in Japan. The patients who died in Korea on the battlefield or at medical installations there are not included.

TABLE 1

Vertebral level and type of injury

Level	Penetrating Wounds	Closed Injuries
Cervical	36	19
Thoracic	135	17
Lumbar	74	10
Sacral	9	0
Total	254	46

TREATMENT

The aim of treatment during this early phase of paraplegic care (average 4–6 weeks) was to salvage as much neurological function as possible and to prevent the formation of decubitus ulcers and other complications that may retard a rehabilitation program. The mortality rate in this series was 1 per cent.

As soon as the patient reached an equipped medical facility a complete physical examination was done, as penetrating wounds of the spinal cord

* Present address: Department of Neurosurgery, Yale University School of Medicine, New Haven, Connecticut.

† The following officers were associated with the author in the care of the casualties on which this report is based: Lt. Col. Arnold M. Meirowsky, M.C., Neurosurgical Consultant, Far East Command, Samuel Atkins, Joseph C. Barnett, Edward J. Bishop, Robert A. Clark, Philip R. Dodge, Griffith R. Harsh, III, George J. Hayes, Milan Leavens, John B. Moyar, Jose Ninecurt, Richard R. Patterson and Paul R. Rosenbluth.

were frequently associated with damage to additional areas. Of the 254 patients with penetrating wounds of the spine 87 (34.25 per cent) had associated chest wounds with hemothorax and/or pneumothorax, 23 (9.05 per cent) had bowel perforations requiring colostomy, 11 (4.33 per cent) had retroperitoneal hematomas without bowel perforations, 10 (3.93 per cent) had perforations of the liver, and 9 (3.54 per cent) had lacerations of the kidney requiring unilateral nephrectomies. Other associated injuries and complications were also present, bringing the total to 194 associated injuries in 164 of the 254 patients who had penetrating wounds of the spine. It is to be noted that some patients had multiple associated injuries. Some of the complications were discovered at a later date, showing the value of an initial and repeated physical examination at frequent intervals. While an injury causing compression of the spinal cord may be considered a surgical emergency, other procedures of a life-saving nature take precedent, and laminectomy may of necessity be delayed several days.

With few modifications the patients in this series received the same treatment as was advocated by many neurosurgeons towards the end of World War II.[4,6,7,11,12,15] In addition to performing laminectomies on all patients with penetrating wounds of the spine, early laminectomies in all cases of closed injuries with fracture-dislocation were also done. Decubitus ulcers were prevented by turning the patient every 2 hours, either by using the double-litter method[1,9] or the Stryker frame. This turning was also continued during air evacuation of the patient back to his homeland. No suprapubic cystostomies were done. Dietary restrictions were practically eliminated by starting early ambulation.[5] Most all of the patients with thoracic or lumbar injuries were fitted with metal long back-braces and started on a sitting-up program on the 10th postoperative day. Plaster of Paris or body casts of other material were not used because they were not deemed necessary for stability and their presence would have made temperature regulation and skin care practically impossible. Whole blood transfusions were given when indicated and no blood substitutes such as plasma were used. The availability of the newer mycin antibiotics and the disc method of culture and sensitivity studies made the treatment of infections much easier than in previous wars. We encountered practically no difficulty with wound healing or infection in those patients who received initial debridement, laminectomy and primary closure of the wound, even at 48–72 hours after injury. Bladder infections were the exception rather than a common finding. The McKenna type of tidal drainage apparatus was used.[8] At times a chest tap for evacuation of a hemathorax or pneumothorax would be followed immediately by a laminectomy.

NEUROSURGICAL INTERVENTION

It may be seen in Table 2 that of the 249 patients with penetrating wounds who had laminectomies, only 44 (17.67 per cent) were operated upon within 24 hours of injury. Of the patients with closed injuries, 17 (56.66 per

TABLE 2

Time interval from injury to laminectomy

Time Interval	Penetrating Wounds	Closed Injuries
Within 24 hrs.	44	17
Over 24 hrs.	205	13
Total laminectomies	249	30
No laminectomy	5	16
Total cases	254	46

cent) of the 30 operated upon had immediate laminectomies. These are overall statistics for the entire period covered in this report. Had neurosurgical teams reached more of the patients on the day of injury, their general condition permitting, the incidence of immediate laminectomies would have been higher. There were 21 patients (Table 2) who did not receive surgery. These were cases in which roentgenograms revealed no bony damage of the spinal canal. Most of these patients initially exhibited evidence of spinal cord damage (concussion) with transitory loss of function followed by remission of symptoms. Spinal manometrics were normal in all these cases. Two patients with fractures of the transverse processes who were treated by tongs and traction only had negative myelograms and persistent neurological deficit (Table 4). At times, because of the large influx of casualties, serious penetrating wounds of the brain were given surgical priority over spinal cord injuries, particularly those below the cervical region. In general, spinal cord injuries were considered surgical emergencies and laminectomies were done immediately. In cases of closed injuries perhaps this was a departure from some of the current concepts of management, particularly in regard to cervical cord injuries.[2,3,10]

In this series, believing that the time element was of considerable importance, immediate laminectomy was deemed advisable prior to attempts to correct the bony deformity. Also, before doing a surgical decompression in the presence of a fracture-dislocation it seemed hazardous to the neural ele-

TABLE 3

Summary of results of treatment in all cases

Results	Penetrating Wounds	Closed Injuries
Improved	121 (25 complete recovery)	26 (8 complete recovery)
Unimproved	130	20
Death*	3	0
Total	254	46

* Cause of death: (1) Pulmonary infarct; (2) ascending arachnoiditis; (3) bilateral kidney lesions.

ments to perform manipulations of the surrounding bone either manually[13] or by extending the manipulation over a longer period of time, as by traction. From this series of 279 laminectomies with no immediate operative deaths (Table 3) it would seem that the risk of a laminectomy is small and in careful hands may prove quite rewarding, as shown in Case 1 below.

Case 1 illustrates the procedure of evaluation of a closed cervical cord injury during the time of this report. The same technique was also used with the substitution of the double-litter turning method by the teams in Korea.

Case 1. Fracture-dislocation of C4–5. Immediate laminectomy. Regain of function.

A 21-year-old, white male private was brought in on a litter 2 hours after he had been injured in an automobile accident in Tokyo.

Examination in the emergency room disclosed loss of motor function below C5, and a sensory level complete at C7 and below, with partial involvement of C5 and C6. There was contusion of the scalp in the occipital area. Respiration was by diaphragm only. Ileus and abdominal distension were present. A #16 French Foley catheter was inserted into the bladder and specimens were saved for culture and urinalysis. Because of the ileus and distended stomach a Levin tube was inserted into the stomach for deflation. The airway proved to be adequate. The patient was then placed face-up on a Stryker frame[14] padded with five pillows laid crossways. An x-ray plate was slipped under the neck and upper chest by depressing the pillows and an A.P. film was taken. The top of the Stryker frame was then attached and the patient was turned face-down. Examination on the dorsal aspect of the patient was then completed. In this position a lateral x-ray of the cervical spine was taken with a portable machine. The wet films revealed a fracture-dislocation of C4–5 with obvious narrowing of the vertebral canal. Blood count, urinalysis, and cross matching of blood were in the meantime performed.

Course. The patient was taken to the operating room (remaining in the face-down position on the Stryker frame). No preoperative medication other than sodium luminal gr. 2 intramuscularly was given.

Operation. A wide decompression laminectomy of C3, C4, and C5 was performed under local anesthesia. The Stryker frame was used in lieu of an operating table. There was a bilateral fracture of the facets between C4 and C5; the laminae, however, were intact. The dura mater was opened and the cord was found to be grossly intact with increased vascularity of the subpial vessels. There was marked angulation of the cord caused by deformity, and several dentate ligaments were therefore sectioned bilaterally.[10] The laceration in the left occipital region was debrided and closed. Crutchfield tongs with 15 lbs. traction were then applied.

Postoperatively the patient regained normal sensation and the ability to void without residual, but generalized weakness persisted for the few weeks he was observed after operation. The strength in the lower extremities was greater than that in the upper extremities.

RESULTS

Cervical injuries (Table 4) accounted for 55 cases (18.33 per cent of the 300 cases in this series). It has been previously stated by some authorities that in cases of acute closed injuries of the cervical spinal cord a complete loss of motor and sensory function is a contra-indication for immediate

TABLE 4

*Treatment and results of cervical cord injuries**

Neurological Deficit on Admission	Type of Injury	No. of Patients	Treatment, and Results on Evacuation from Tokyo								
			No Surgery			Laminectomy			Tongs-Traction Only		
			Un-imp.	Imp.	No Defi-cit	Un-imp.	Imp.	No Defi-cit	Un-imp.	Imp.	No Defi-cit
Transitory long-tract signs or nerve root involvement	Closed	6			3						3
	Pent.	2			2						
Partial lesion	Closed	4		1	1		1			1	
	Pent.	14					10	4			
Complete loss of function below level of injury	Closed	9				3	4		2		
	Pent.	20				7	12	1			
Total		55	0	1	6	10	27	5	2	1	3

* In Tables 4–7, Unimp. = unimproved; Imp. = improved; No deficit = no residual neurological deficit, complete recovery.

laminectomy. In this series there were 9 patients with cervical spine fractures who had on initial neurological examination a complete deficit below the level of injury. Of these, 7 had laminectomies. The remaining 2 were

TABLE 5

Treatment and results of thoracic cord injuries

Neurological Deficit on Admission	Type of Injury	No. of Patients	Treatment, and Results on Evacuation from Tokyo					
			No Surgery			Laminectomy		
			Unimp.	Imp.	No Deficit	Unimp.	Imp.	No Deficit
Transitory long-tract signs or nerve root involvement	Closed	3			3			
	Pent.	2			2			
Partial lesion	Closed	2				1	1	
	Pent.	10					8	2
Complete loss of function below level of injury	Closed	3				1	2	
	Pent.	107	1*			96	9	1
Total		127	1	0	5	98	20	3

* Negative myelogram and no fracture on X-ray.

TABLE 6

Treatment and results of lumbar cord or conus injury

Neurological Deficit on Admission	Type of Injury	No. of Patients	Treatment, and Results on Evacuation from Tokyo					
			No Surgery			Laminectomy		
			Unimp.	Imp.	No Deficit	Unimp.	Imp.	No Deficit
Transitory long-tract signs or nerve root involvement	Closed	1			1			
	Pent.	0						
Partial lesion	Closed	6					6	
	Pent.	14					12	2
Complete loss of function below level of injury	Closed	7				4	2	1
	Pent.	19				16	2	1
Total		47	0	0	1	20	22	4

treated with tongs and traction only. Four of the 7 who had laminectomies showed improvement of the immediately adjacent cervical nerve roots and the long tracts of the spinal cord:

1. C4–C5 fracture-dislocation (Case 1 above). Regained normal sensation and ability to void but generalized weakness persisted for the few weeks he was observed postoperatively.

2. Compression fracture C5. Immediate operation with marked motor and sensory improvement to T4.

3. Compression fracture-dislocation of C5–C6 with postoperative regain of partial function of all dermatomes and myotomes.

4. Compression fracture C4–C5 with signs of regaining sensation all the way down plus ability to move upper extremities.

The patients with penetrating wounds of the cervical spine showed an even brighter picture. All 20 of those patients who had complete loss of motor and sensory function below the level of injury were operated upon and 13 showed improvement. One patient was ambulatory with slight weakness in the legs 3 weeks after injury. Even in the patients in whom no improvement was noted in the long tracts of the spinal cord, laminectomies and decompression of involved nerve roots in the cervical region frequently lowered the dermatome level by one or two segments. This allowed the patient some or better use of his upper extremities. While this series is too small to make any definite conclusion it appears to indicate that by an immediate laminectomy some patients may be saved from a life of quadriplegia. There were no operative mortalities among the 42 cervical laminectomies of this series.

Thoracic injuries (Table 5) accounted for 127 cases (42.33 per cent). These wounds were frequently associated with concomitant lesions in the

TABLE 7

*Treatment and results of cauda equina injuries**

Neurological Deficit on Admission	Type of Injury	No. of Patients	Treatment, and Results on Evacuation from Tokyo					
			No Surgery			Laminectomy		
			Unimp.	Imp.	No. Deficit	Unimp.	Imp.	No Deficit
Transitory long-tract signs or nerve root involvement	Closed	0						
	Pent.	0						
Partial lesion	Closed	4			1	1	1	1
	Pent.	23				1	15	7
Complete loss of function below level of injury	Closed	1				1		
	Pent.	43				20	20	3
Total		71	0	0	1	23	36	11

* Cauda equina without cord or conus involvement.

thoracic and abdominal cavities, often necessitating a delay in laminectomy. To my knowledge none of these patients was wearing one of the armored vests which were issued during the later stages of the Korean conflict. Perhaps the delay in performing the laminectomies on 109 patients who had complete motor and sensory loss is one of the reasons why only 12 (11.01 per cent) showed postoperative improvement. The above is in contradistinction to the 27 cervical laminectomies (Table 4) on patients with complete loss of function below the level of injury of whom 17 (62.96 per cent) showed postoperative improvement in neurological function.

Lumbar cord-conus injuries (Table 6) accounted for 47 cases (15.66 per cent). All except 1 patient in this group had a laminectomy. Of the 26 patients who had a complete loss of neurological function prior to laminectomy only 6 (23.07 per cent) showed postoperative improvement.

Cauda equina injuries (Table 7) represented 71 cases (23.66 per cent) of the series. All except 1 of the 4 patients who had a closed injury with partial deficit and negative myelogram received laminectomy. Of the 44 patients who had complete loss of neurological function below the level of injury 23 (52.22 per cent) showed improvement during the postoperative stay in Tokyo. Three were ambulatory.

A survey of the *over-all results* of treatment of patients with a complete neurological deficit below the level of injury shows that improvement during the immediate postoperative period was best in the group of cervical cord injuries. This was followed in order by cauda equina, lumbar cord-conus, and thoracic groups. No doubt the eventual recovery over a longer period of time would be best in the cauda equina group.

Factors in Mortality. While it has been stated above that there were no deaths in this series immediately attributable to the performing of a laminectomy, there were 3 patients who died during the course of hospital treatment and their deaths must be considered as operative mortalities. Their causes of death as determined by autopsy were:

1. Pulmonary infarct 24 days after laminectomy in a patient who had a penetrating wound of the spine at T12-L1 and multiple wounds of the back and arm with fracture of the left humerus.

2. Ascending adhesive arachnoiditis with respiratory paralysis 1 month after penetrating wound of the spine at T2.

3. Bilateral kidney damage requiring the removal of one kidney with uremia 5½ months after sustaining a penetrating wound of the abdomen and spinal canal at T12–L1.

SUMMARY

A series of 300 consecutive patients with spinal cord injuries admitted to the Tokyo Army Hospital from September 1950 to May 1952 are evaluated. The over-all mortality in this series was 1.0 per cent.

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THE SYNDROME OF HERNIATION OF THE LOWER THORACIC INTERVERTEBRAL DISCS WITH NERVE ROOT AND SPINAL CORD COMPRESSION

A PRESENTATION OF FOUR CASES WITH A REVIEW OF THE LITERATURE, METHODS OF DIAGNOSIS AND TREATMENT*

JOSEPH A. EPSTEIN, M.D.

Division of Neurological Surgery, Department of General Surgery, St. John's Episcopal Hospital, Brooklyn, New York, and the Long Island Jewish Hospital, New Hyde Park, New York

(Received for publication July 13, 1954)

THE grave sequelae following operations on protruded thoracic intervertebral discs have cast a pall over those attempting surgery for the relief of this disorder. Unfortunately, laminectomy or attempts at removal of the protruding ridge at the intervertebral space have been made hazardous by a combination of factors. These include advanced alterations in the spinal cord caused by prolonged compression of the tissue or of its blood supply. The anatomical disadvantages facing the surgeon when operating in the narrowest portion of the spinal canal make the cord unusually vulnerable to the slightest untoward manipulation. The only reports bearing a note of optimism are those of Love and Kiefer[9] and Logue.[8] While confirming the gravity of the problem, they nonetheless indicated that it was possible to make an accurate pre-operative diagnosis and to operate successfully on a significant number of these patients.

In the cases presented herein, a variety of abdominal complaints, back pains and obscure neuralgias beclouded the actual pathology. A neurogenic etiology was considered as a last resort only after pyelograms, gastro-intestinal and gallbladder series failed to aid in establishing a diagnosis. At times, minor alterations in the uterus or in other organs were seized upon and unnecessary surgical procedures performed. This occurred in 2 of the cases and was only narrowly averted in a third.

It is understandable why a lesion of the intervertebral disc can be overlooked since even a careful neurological examination may disclose only the slightest deviation from normal. Most important is the awareness of the possibility of nerve root compression in the thoracic region despite the absence of gross neurological deficit. In this regard, it is mandatory to make a careful examination of the spine roentgenographically and to perform myelography when the situation is of sufficient gravity to justify this procedure. If

* Presented before the New York Society of Neurosurgery, April, 1954.

the diagnosis can be established before signs of cord compression occur, operative results should improve. Surgery will not be made overly hazardous because of insurmountable tissue alterations or jeopardized by an irreparably injured spinal cord. A similar pattern has evolved in the surgery of the cervical intervertebral disc and it is anticipated that a more optimistic future lies ahead in the treatment of the same problem in the thoracic spine.

In 3 of the following cases early evidence of nerve root compression by a protruding intervertebral dic was the most conspicuous and disabling symptom. All patients were benefited by surgery, to a gratifying degree when radicular symptoms were the dominant factor. Signs of compression of the spinal cord were minimal and reversible in 2 of this group. In a fourth patient, pain was completely absent, the primary alteration occurring in the spinal cord. In this patient, while permanent damage to the cord exists, improvement has made it possible for him to resume satisfactory gainful employment.

CASE REPORTS

Case 1. B.O., a 55-year-old housewife, complained of painful, disagreeable sensations over the skin covering the lower abdomen on the right side for the past 15 months. This later became deep and boring in character, at times sharp and crushing. The pain was spontaneous in onset, appeared intermittently at first but soon became constant. Pain increased in intensity to the point of total incapacitation. There was no weakness or numbness, and there were no alterations in sphincteric function. Straining did not alter the character of her symptoms but movement such as turning in bed did.

A benign pericardial cyst was discovered on routine chest films and 5 months after the onset of her symptoms a left thoracotomy was performed with the removal of the 6th rib. Following this procedure, vague pain and discomfort were appreciated in the area of distribution of the intercostal nerves sectioned at operation. There was no relief of her presenting complaints. Repeated gastro-intestinal series, gallbladder studies and intravenous pyelography were negative.

Neurological Examination. She was an unusually tense and anxious woman complaining of severe pain on the right side extending from the upper lumbar region anteriorly to her lower abdomen, radicular in character. A band of hyperalgesia could be defined over the course of the 11th and 12th thoracic nerves both dorsally and ventrally on the right side. There was anesthesia over a band of skin in the left thoraco-abdominal region conforming to the area denervated by interruption of the intercostal nerves at thoracotomy.

Roentgenograms of the entire spine were negative. Lumbar puncture disclosed normal CSF pressure and manometrics. The spinal fluid was clear and colorless with a protein content of 50 mg. per cent. The cell count was normal. Myelography disclosed a constant defect in the column of oil at the thoracic 11–12 interspace (Fig. 1A). With increasing the tilt of the table, oil flowed by the defect in a narrow stream on the left side only. The diagnosis of an extradural tumor was made, possibly a neurofibroma of the 11th thoracic nerve.

Operation, Nov. 15, 1952. Laminectomy of thoracic vertebrae 11 and 12 was per-

formed. The dura mater was opened, disclosing a conspicuous hump in the cord caused by a mass anterior and lateral to the dural sac on the right side. It was rubbery in consistency and was exposed by turning the dural retention sutures to the left with gentle retraction on the dural envelope. The lesion consisted of a protruding disc causing the annulus to bulge prominently, fragmenting its fibers and leaving degenerated disc tissue apparent at the surface. The break was enlarged and all abnormal disc tissue was removed. Remnants of the annulus and the bony spurs at the vertebral margins were bitten away and the area was leveled. The dorsal fibers of the involved nerve were then sectioned intradurally.

Postoperative Course. The patient was considerably improved and left the hospital 12 days after operation.

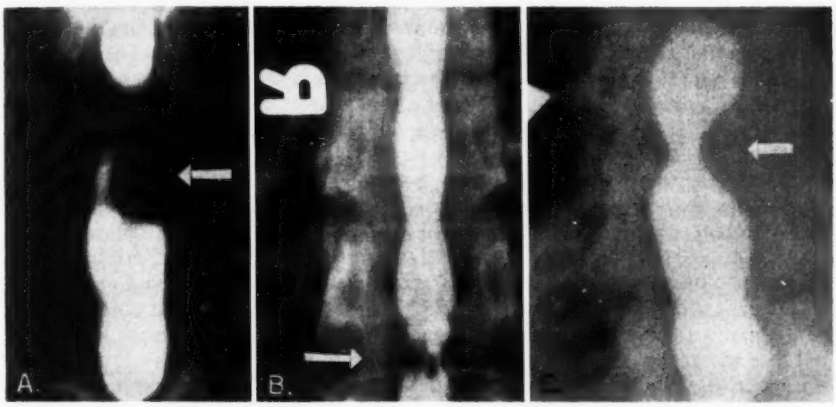

FIG. 1. (A) *Case 1.* Myelographic defect at the T11–12 interspace. (B) *Case 2.* Defect at T12–L1 interspace. Compare with full contours of column at the upper two interspaces. (C) *Case 4.* Defect at T11–12 interspace.

Subsequently, she has complained of girdle-like, pressing pains on the left side across the lower thorax and beneath her breast. Similar pain, although of lesser intensity, appeared later on the right side as well. Pain followed the course of the intercostal nerve previously sectioned. The intercostal neuralgia has proven intractable to all measures and has persisted in an extremely disturbing degree. There has been no evidence of return of symptoms in the lower abdomen on the right side.

Case 2. F.R., a 30-year-old woman clerk, complained of intermittent pain in the right lower quadrant of her abdomen for the past 3 years. Pain was most severe during her menstrual periods and at the time of ovulation. One and one-half years after onset the pain had increased in intensity and involved the right lumbar region, from which it spread into the right lower abdomen and down the anterior and medial aspect of her thigh in a radicular pattern. It was described as "burning" and "pushing," appearing either as severe spasms or as a constant sensation. While not precipitated by straining, effort of this type aggravated pre-existing discomfort. She complained of occasional numbness in the right groin and in the right side of her vagina, as well as of unusual sensitivity of the skin over the lower abdomen. During

the preceding month, there was difficulty in initiating urination. She was severely constipated and had to resort to manual pressure over her buttocks to force feces from her rectum. She found it impossible to have intercourse because of severe intractable pain caused by the act and by any position in which it was attempted. The day prior to admission she was aware of numbness in both inguinal regions as well as in the perianal area on the right.

Pain was progressively more severe and incapacitating. Cystoscopy and retrograde pyelography were normal. The possibility of endometriosis was entertained and exploratory laparotomy was being considered because of a past history of pelvic inflammatory disease. There was no history of trauma.

Neurological Examination. There was a band of hyperalgesia and hyperesthesia conforming grossly to the 12th thoracic dermatome on the right with an area of hypesthesia and hypalgesia spreading down the medial aspect of the thigh and over the skin adjacent to the anus on the right. Deep tendon reflexes were of normal intensity. Superficial abdominal reflexes were intact and plantar responses were normal. Manipulation of the hip elicited no discomfort. Straight leg raising as well as movement of the spine was unrestricted. There was no unusual spinal or paraspinal tenderness.

Roentgenograms of the spine were not remarkable except for small anterior osteophytes in the dorsal region. Lumbar puncture disclosed a normal spinal fluid with a protein content of 41.2 mg. per cent. Manometrics were normal. Myelography revealed a partial block between the 12th thoracic and 1st lumbar vertebra at the level of the interspace (Fig. 1B). The pantopaque passed over this hump in the left lateral gutter and pooled without further incident in the cervical canal. The entire lumbar area was normal in appearance. The diagnosis of herniated intervertebral disc was made.

Operation. Total laminectomy of the 12th thoracic and the 1st lumbar vertebra was performed. The dura mater was opened, disclosing the cord to be humped over a rubbery extradural ridge of tissue extending from the extreme right well to the left of the midline. The mass was then exposed by reflecting the dural retention sutures to the left and retracting the cord gently. This was facilitated by removing the lamina far to the right. The previously identified hump was observed to be caused by a bulging, thinned-out annulus which ruptured on the slightest pressure of bayonet forceps. There resulted a spontaneous herniation of yellow-grey, soft, amorphous tissue from the interspace. The entire protrusion was leveled, using pituitary forceps to evacuate the interspace and to bite off the marginal osteophytes at the rim of the vertebrae. The dura mater was re-opened and the dorsal fibers of the involved nerve root at this level were sectioned. The dura mater was then closed.

Postoperative Course. The patient no longer complained of the back and abdominal pain and she was discharged 3 weeks later.

Her menses have since been without unusual pain or discomfort. Intercourse is no longer painful. Urination and defecation are normal. There is still a sensation of hyperesthesia over a small area of the lower abdominal wall on the right. No loss of sensation could be discerned postoperatively despite the rhizotomy. The patient resumed her former occupation and was without complaints 7 months after surgery.

Case 3. F.K., a 54-year-old woman, 4 months before examination noted the spontaneous onset of spasmodic pains in the upper lumbar region of her back radiating around both sides of her abdomen into the groin. They were more severe on

the left side. Pain would appear abruptly and last about one-half minute. It was of agonizing intensity. There was no increase in frequency of attacks or alteration in the character of the pain with the passing of time. She described the pain as being similar to a labor pain. It was not affected by position, lifting, straining or by her menstrual periods, which were regular and of normal pattern.

An enlarged, tender uterus had been discovered at an earlier examination. The patient entered the hospital for hysterectomy and salpingo-oophorectomy, which was performed on Dec. 30, 1952. Pain continued unchanged following surgery.

Neurological examination on Jan. 5, 1953 disclosed brisk deep tendon reflexes in all extremities, those in the lower left limb being a shade more active than the others. Sensation was intact and there was no evidence of weakness. A constant finding was a Babinski sign on the left. Percussion over the midlumbar spine was slightly more uncomfortable than elsewhere.

Roentgenograms of the spine disclosed large anterior and smaller lateral osteophytes in the lower dorsal region with some bridging. Similar although less pronounced alterations were seen in the lumbar spine. Lumbar puncture showed normal CSF pressure with normal responses on jugular compression. The total protein was 33.6 mg. per cent. Myelography, using 6 cc. of pantopaque, showed a definite and constant defect in the column of oil at the interspace between the 11th and 12th thoracic vertebrae (Fig. 2). The diagnosis of a possible herniated disc with radicular and spinal cord involvement was made.

Course. The patient was discharged from the hospital and returned in 2 weeks unchanged except that there was now a questionable deficiency in the appreciation of pinprick over the lateral aspect of the left lower limb with a poorly defined sensory level at the umbilicus.

Operation. Laminectomy of the 11th and 12th thoracic vertebrae was performed. The dura mater was opened disclosing a conspicuous bulge anterior to the dura mater on the left side, elevating the nerve root and the cord. The dura mater was reflected towards the right and the protruding annulus was exposed. It was unusually thin and friable and when perforated with forceps, a considerable quantity of amorphous, degenerated disc tissue was removed from the interspace. Osteophytes at the vertebral margins were removed with pituitary forceps. Section of the dorsal fibers of the nerve displaced by the mass was performed intradurally. The dentate ligaments in the exposed area were then cut and the dura mater was closed.

Postoperative Course. The patient complained only of occasional twinges of pain across her back and spreading into her groin. These disappeared prior to discharge. A sensory deficit extending from her lower abdomen across the upper and medial aspect of the left thigh over at least three dermatomes persisted after surgery.

Six weeks after operation, she experienced peculiar tingling and pins-and-needles sensations in her right foot. These would first be felt in her toes and then would rise up to her groin. There were occasional cramping pains in the muscles of the calf and thigh. Episodes would occur periodically without warning, at times being precipitated by turning or twisting.

Neurological examination showed no alterations in the abnormalities previously discerned. Sensory examination during one of the episodes disclosed no changes. Fluoroscopy of the spine was repeated using the residual pantopaque, approximately 1 cc. This revealed no delay or gross deformity at the operative site. There were

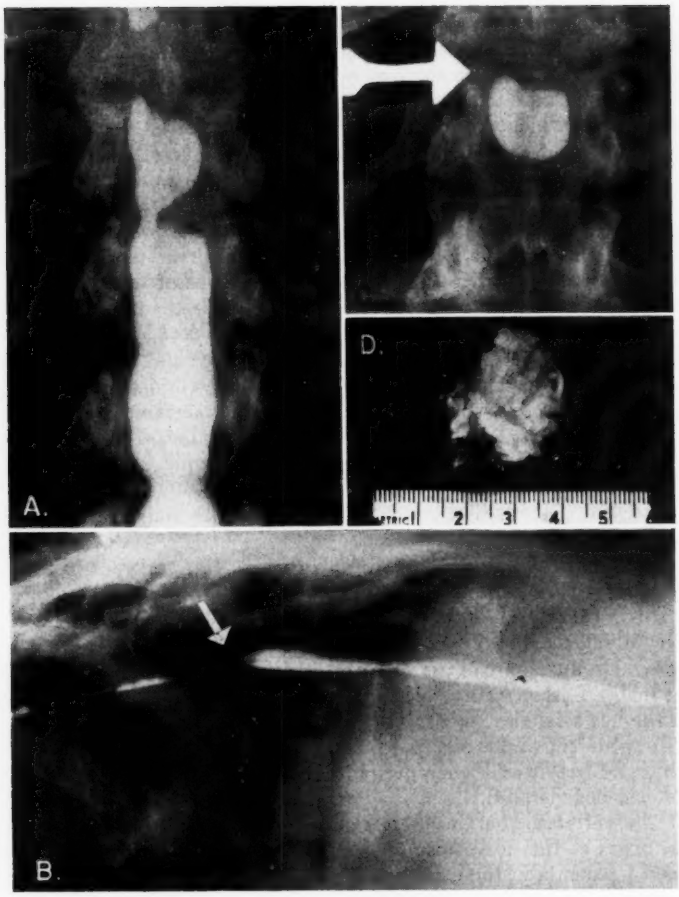

FIG. 2. *Case 3.* (A) Sharply defined, almost transverse defect in myelogram at T11-12 interspace. (B) Lateral exposure showing pooling of oil at this interspace where it collects in a pattern characteristic of a partial obstruction in the ventral quadrants of the spinal canal. (C) Pool of oil hanging suspended at the interspace level despite a 70° cephalad tilt of the table. (D) Operative specimen.

only scattered tiny droplets of pantopaque in the tissues in the vicinity of the operation.

The paresthesias became less severe and 6 months later subsided. One year after operation, the sensory deficit over her lower abdomen and thigh was still present. The Babinski sign had disappeared. The cause of the paresthesias remains obscure, possibly being related to operative trauma with subsequent arachnoiditis.

Case 4. V. W., a 52-year-old bus driver, noted progressive weakness of his right lower extremity for the past 1½ years with unsteadiness of gait and numbness over

the right thigh and calf. Weakness had become incapacitating and he could no longer be employed in any occupation requiring him to stand or walk. He complained of difficulty in urinating and could not void in any position except standing. He did not complain of pain. Three years previously he had twisted his back while trying to avoid a falling door but there were no apparent sequelae to this injury.

Neurological Examination. There was no abnormality in the upper extremities. Deep tendon reflexes in the lower limbs were hyperactive with bilateral ankle clonus and Babinski sign. Superficial abdominal reflexes and cremasteric reflexes could not be elicited. There was a definite sensory level to pain and touch below the umbilicus on the right side with incomplete involvement of the sacral dermatomes, the penis and immediate perianal area being excluded. Vibration and position sense were markedly impaired to lost in the toes on the right and diminished on the left. The patient limped, favoring the right lower limb, the gait being spastic, unsteady and wide-based.

FIG. 3. *Case 4.* Scoliosis of spine with apex of curve at the T11–12 interspace (arrow). Note myelographic defect at this level in Fig. 1C.

Roentgenograms of the entire spine by Dr. A. L. Loomis Bell disclosed evidence of hypertrophic osteo-arthritis localized to the adjacent aspects of the 11th and 12th dorsal vertebrae with a scoliosis of the spine having its turning point at this level (Fig. 3).

Lumbar puncture disclosed normal fluid, pressure and manometrics. The spinal fluid protein was 26 mg. per cent.

Pantopaque myelography disclosed a constant obstruction to the flow of oil at the thoracic 11–12 interspace crossing the midline and obstructing the cephalad flow until the table was tilted sharply downward, when the column of oil was observed to pass by the obstruction on the left (Fig. 1C). The findings were consistent with the diagnosis of a lesion at the interspace, either a herniated disc or a ridge formed by osteophytes at this level.

Operation. Laminectomy of thoracic vertebrae 11 and 12 was performed. A distinct paucity of epidural fat was observed. The dura mater was opened and the cord was noted to be elevated by an extradural ridge crossing from right to left, most prominent on the right. It was elastic in consistency. The mass was then exposed extradurally and identified as herniated disc tissue that had partially ruptured through a torn annulus, pushing the posterior longitudinal ligament before it. The ligament was opened and a moderate amount of degenerated disc tissue was removed. In addition, osteophytes protruding from the lips of the vertebrae were bitten away with pituitary forceps. The dura mater was closed.

Postoperative course was uneventful. After discharge motor power improved

steadily. Urination returned to normal. Position and vibratory sense returned with only a minimal residual deficit on the right. Hyperactive reflexes have persisted in the lower limbs but are of lesser intensity, ankle clonus disappearing on the left. The plantar responses have remained extensor. Gait has improved and the patient is now employed as a salesman 1 year after surgery. He is on his feet for considerable periods and can walk 10 to 16 city blocks without unusual effort. Residual weakness persists on the right.

DISCUSSION OF CASES

The number of cases is too small to provide any valid analysis of such factors as sex, age, occupation or constitution. The women were from 30 to 55 years of age and the male was 54. Symptoms had been present for periods of from 4 months to 3 years and were progressive in nature in 3 of the 4 patients. In no case was trauma an etiological factor.

Three of the patients were women performing housework or acting in a clerical capacity. Each complained of severe incapacitating pain, radicular in nature. It was intermittent and of varying frequency, with a tendency to become constant in 2. In the youngest of the 3 women, pain was adversely affected during periods of ovulation and preceding menses. The similarity of the pain to a labor pain was commented on twice. Its abrupt onset was common to all and such words as crushing, sharp, burning and pushing were used to describe its character. Straining aggravated the pain in only 1 patient. Twisting and turning movements of the back precipitated pain in 2. One of the women complained of difficulty in initiating the urinary stream. Numbness of the skin of slight degree was felt in the lower abdomen and groin in 1 case. This woman complained of hypersensitivity of the skin and other irritative phenomena during the examination, as did another. Symptoms were unilateral for the most part.

The painless onset of a spastic, ataxic gait was the only complaint of the male member of the group. This was progressive with subsequent development of weakness, a sensory level at the 10th thoracic dermatome and sphincteric disturbances.

Of the 3 female patients, hysterectomy had been performed in one, a benign pericardial cyst was removed in another and a contemplated exploratory laparotomy was averted in the third.

Neurological examination of the first 2 patients showed evidence of nerve root irritation with hyperalgesia and hyperesthesia over lower thoracic dermatomes. Vague areas of diminished sensation were found in more distal areas. In 1 of these women, sphincteric changes suggested cord involvement. The third woman showed evidence of pyramidal tract disease. The male patient demonstrated evidence of intrinsic cord disease at a definite level.

Plain roentgenograms of the spine were of assistance in only 1 case showing scoliosis and hypertrophic osteo-arthritis localized to the adjacent aspects of the 11th and 12th dorsal vertebrae. The findings on lumbar puncture were normal with no evidence of block or unusual elevation of spinal

fluid protein. Clinical findings were at best suggestive, myelography establishing the diagnosis in each case. Fluoroscopy was most important and showed the moving column of oil to halt at the level of the interspace concerned. With further tilt of the table, the pantopaque was observed to flow around the partial block in the lateral gutter opposite the obstructing ridge. Spot films taken in lateral as well as in the anteroposterior projection confirmed the relation of the block to the interspace. The lateral exposure demonstrated the location of the pathology anterior to the cord. Such defects were found at the interspace between the 11th and 12th thoracic vertebrae in 3 patients and at the next lower interspace in the fourth.

The pre-operative diagnosis of an extradural tumor was made in the first patient seen with this syndrome. The roentgenograms were considered specific enough for the diagnosis of a protruding disc in the remaining 3 patients.

Operation was performed using general endotracheal anesthesia with the patient in the crouch position, the back well arched and the buttocks supported on a small seat avoiding pressure on the popliteal space. Bleeding intraspinally was minimal and easily controlled under these circumstances since the abdomen was not compressed in any way. Total laminectomy of at least two vertebrae was performed, being carried far lateral to the side of greatest involvement in order to facilitate exposure and to make the approach to the anterior and lateral aspect of the canal easier. The dura mater was opened in all cases prior to exposing the actual lesion. The cord was examined for gross alterations and any disturbance in its normal contour was noted. This aided in identifying the exact location of the ridge lying anterior to the cord and unnecessary manipulation was avoided in seeking for it extradurally. Once identified, bony exposure was enlarged if needed. The cerebrospinal fluid drained away. The dura mater was temporarily closed and retracted away from the lesion by turning the stay sutures along its open margins to the opposite side. This reduced the bulk in the canal and only gentle pressure with a thin elevator sufficed for exposure. The bulging, attenuated and often ruptured annulus was perforated with bayonet forceps, the opening was enlarged and the protruding, degenerated disc tissue and contents of the intervertebral space were removed. This was performed with pituitary forceps of 2 to 3 mm. diameter, angulated to facilitate this procedure as the midline was approached. Marginal osteophytes were removed in a similar manner, the greatest care being taken to leave no projecting bony ridge in the lateral and more medial surfaces of the canal. No chisel or sharp curette was used. In 1 case, the denticulate ligaments were severed. In all cases of radicular pain the dorsal roots of the nerve involved were cut intradurally. The dura mater was closed with interrupted sutures and the wound was closed without spinal fusion.

Postoperatively, relief of the radicular pain was achieved. Dermatome anesthesia was present in only 1 of the 3 patients in whom rhizotomy was performed, the others showing little or no residual deficit. Signs of cord com-

pression were relieved in 2 of the female patients, 1 with sphincteric changes and the other with long tract signs. The patient with a transverse cord lesion showed a partial return of function.

REVIEW OF THE LITERATURE

Discogenic disease of the thoracic spine has received relatively little attention when compared to the large number of publications concerned with lumbar and cervical disc pathology. This is not surprising since the clinical syndrome heretofore has been regarded as unusually rare and obscure. An analysis of the literature and the present cases discloses that certain clinical features are held in common. An appreciation of these findings should enable the practitioner to suspect the diagnosis more often and to confirm it with the proper ancillary studies.

No attempt is made to discuss in detail the frequency of this lesion in the thoracic spine as compared to other levels since the reports vary greatly in this respect.[4,5,8–13] We have until now been unable to recognize the syndrome with sufficient accuracy, thereby allowing a significant number of cases to pass by undiagnosed or misdiagnosed. In a postmortem study of 99 unselected spinal columns, protrusions of thoracic discs were found in 7, of cervical discs in 53 and of lumbar discs in 27.[4] While multiple involvement was relatively frequent in the cervical and lumbar spine, it was rare in the thoracic spine. About one-third of the protrusions into the spinal canal formed transverse ridges with a bulging but intact annulus. Disc degeneration occurred with greatest frequency in the more mobile segments of the spine, namely the lower cervical, lower thoracic and lower lumbar regions. The frequency of disc degeneration with ridge formation and actual herniation at the 11th thoracic interspace is significant and deserves emphasis.[9,13]

PATHOLOGY

Degenerative changes in the intervertebral discs occur relatively early in life with a steady loss of water content altering normal elasticity and turgor, resulting in narrowing of the interspace. With increasing age, the inner layers of the annulus fibrosus ultimately merge with the nucleus, leaving only a rim of the original tissue. As the disc becomes thinner, the daily trauma of living is borne in greater part by the attenuated fibrocartilaginous annulus. The annulus bulges outward, resulting in an abnormal strain on the attached spinal ligaments, loosening their connections to the periosteum which covers the ring epiphysis. This causes an elevation of the periosteal layer with the formation of osteophytes constructed of new bone laid down between the elevated periosteum and the original corticalis of the vertebra. Since the calcium content of this marginal area of newly formed bone does not reach an immediate maximum, x-ray changes may not be apparent until relatively late. This explains the finding of formidable ridges at operation when only minimal alterations were discerned in the routine roentgenograms. These ridges may occur laterally in the canal but more commonly traverse the mid-

line and involve both sides. When ridges project into the spinal canal from the posterior margins of the vertebral bodies or from the facets of the apophyseal joints, the intervertebral space becomes narrow and foraminal constriction results. The neurological abnormalities appear to be a direct result of mechanical constriction of the spinal cord and nerve roots and possible interference with their blood supply by osteophytes formed at the posterior margins of the vertebral bodies.[1,7]

CLINICAL FEATURES

Of the cases reported, men are affected with greater frequency than women in a ratio of approximately 5 to 3. It is a disease of middle and late adult life, the average age being 50 years.[8] The patient of 30 in the present group would be considered unusual in this regard but not if one considers the fact that symptoms lasting as long as 10 years were noted in cases of Logue[8] and Müller.[12] Trauma is of no special significance and neither is occupation, body habitus or heredity.

The history of radicular pain cannot be emphasized enough. This occurs when the projection of tissue at the interspace encroaches on the contents of the intervertebral foramen, and is found in about one-half of the cases. It may be accentuated by movements of the spine and by coughing. In the upper thoracic spine, the pain may be girdle-like and not necessarily complete since only part of the distribution of a root may be involved. Pain may, therefore, radiate to an intercostal space or to the back. Since the lowest segments are most frequently affected, pain radiates to the abdomen and groin, simulating disease of the abdominal viscera, especially the kidney. Pain restricted to the midline of the spine or slightly to one side has also been localized to the upper lumbar or thoracolumbar regions, irrespective of the level of the prolapse.[8] Local tenderness on percussion of the spine at the level of the pathology also occurs.

The sensory alterations found in the affected segment are either an increased skin sensitivity or a partial numbness indicative of nerve root irritation or destruction. Segmental loss of the superficial abdominal reflexes may occur and aid in localization.[8,12,13] The midline protrusion may be insidious in onset, painless and manifested only by symptoms and signs of spinal cord compression. These include a spastic, ataxic gait caused by interference with pyramidal and spinocerebellar pathways. Poorly defined sensory levels, at times above or far below the actual level of the lesion, have been described.[5,8] Sphincteric changes occur but are not a conspicuous part of the syndrome which resembles closely that caused by similar lesions in the cervical spine.[2,3] Combinations of both radicular and spinal cord pathology occur since ridges frequently extend both medially and laterally. A Brown-Séquard syndrome has been found with lesions anterolateral to the cord, much as it occurs in the cervical spine.[8,9,12] Radiation of pain in the distribution of the lumbar nerves with lesions at the 11th and 12th thoracic interspaces is explained by the fact that it is anatomically possible for a prolapse at these levels to

involve the majority of the lumbar and also the upper sacral nerve roots, as these lie closely applied to the conus medullaris.[8]

LABORATORY STUDIES

Lumbar puncture may disclose varying degrees of block on jugular compression. Total block frequently occurs with the more advanced type of transverse lesion in which cord function is seriously compromised. With the more laterally placed lesions, lesser degrees of block to an open manometric system is the rule. In the early stages, manometrics and spinal fluid chemistry are usually entirely normal.[8,9,12] With the presence of a block, protein values in the spinal fluid may rise to as high as 400 mg. per cent.[9]

Roentgenograms of the spine may prove of value if a positive finding such as calcification of the intervertebral disc is found at the suspected segmental level.[8,9,12] This was found in 8 of the 11 cases described by Logue,[8] who also studied 100 unselected thoracic spine films of a similar age group and observed nuclear calcification in only 4 instances. In 1 case described by Love and Kiefer[9] the calcified disc had herniated into the spinal canal anterior to the cord, and operation without myelography provided the patient with immediate relief of pain and disability. Lipping of the vertebral margins is not unusual at multiple levels of the spinal column. When restricted to a specific interspace and associated with symptoms suggesting an abnormality at this level, it must be regarded with suspicion.

Myelography has proven of inestimable value in establishing the preoperative diagnosis with sufficient accuracy to enable one to proceed with advantage early in the course of the disease. A partial or complete block is characteristically found in the cephalad flow of pantopaque at the level of the interspace involved. The defect is smooth, semicircular or oval in shape and typical of an extradural lesion. Lateral exposures can be taken while the oil is suspended at the interspace, be it only temporarily, and these demonstrate the obstruction lying anterior to the cord, outlining the silhouette of the ridge with unmistakable clarity. Fluoroscopy is mandatory and will reveal the lesion at levels where it may be difficult or impossible to retain the oil long enough to take films.

DIFFERENTIAL DIAGNOSIS

When pain was not a conspicuous factor, the presence of remittency in symptoms has led to the diagnosis of multiple sclerosis in a good number of patients.[8,10,12] Normal spine films and spinal fluid supported this diagnosis. This again indicates, as in similar lesions of the cervical spine,[2,3] that when the syndrome is limited to the spinal cord, myelography should be performed. The diagnosis of a myelopathy is not unusual in cases in which symptoms have appeared over a short period of time. This may occur with disc lesions as a result of direct cord compression or by interference with circulation. It may be impossible to differentiate the lesion from a spinal cord tumor even on myelography, although spinal fluid findings may be of value in this

regard. When radicular pain dominates the picture, a host of abdominal complaints of visceral origin may be simulated, usually intractable to all forms of therapy and unresolved by all of the usual diagnostic aids. Intercostal neuralgia, pleurodynia, renal colic, angina and fibrositis are easily mimicked when nerve root irritation occurs. Radicular paresis and atrophy of the intercostal and abdominal muscles usually pass unobserved and even segmental sensory changes easily escape notice.

TREATMENT

No conservative, nonsurgical methods of therapy have been described. As in cases of cervical disc lesions, when the protrusion is far lateral and only nerve root compression exists, the situation is not urgent and the decision to operate should depend on the amount of disability caused by pain. When the spinal cord is involved, surgical decompression should be contemplated early before irreversible alterations occur. The specific technique employed in the present cases wherein radicular compression is the primary factor has been described earlier. An accurate pre-operative diagnosis is most important since irreparable harm to the cord can occur when rongeurs are inadvisably placed beneath the lamina overlying the lesion, crushing the cord against the underlying ridge. Undoubtedly, many of the adverse effects of surgery can be related to this unfortunate occurrence.

Hemilaminectomy has been described by Love and Kiefer[9] as sufficient for exposure of the laterally lying disc, laminectomy being reserved for those cases in which there is spinal cord compression. Simple uncapping of the involved nerve root has been performed by Young[13] for cervical and thoracic discs. Dorsal rhizotomy is indicated for the laterally lying protrusion in order to insure relief of pain. Logue[8] does not hesitate to remove the pedicle on the side of maximum protrusion. The denticulate ligaments are divided to lessen traction on the cord and to permit greater freedom of movement. The ligaments have been implicated by Kahn[6] to explain by stress analysis the frequency of pyramidal tract signs in anterior compression syndromes of the spinal cord.

If there is an area of necrosis in the cord, this is a most ominous sign even when the associated neurological deficit is not severe and under these circumstances a decompression is all that should be done. If the cord is not abnormal and the prolapse is accessible and soft, all of it should be removed. When a transverse bony spur is found it may be wiser to avoid radical excision in favor of simple decompression.[8] The latter need not necessarily be so limited since such spurs may be bitten away with pituitary forceps if proper precautions are taken in making the exposure and in protecting the cord. As instrumentation improves, this may be made easier and less traumatic. Chisels and sharp curettes carry too great a hazard in their manipulation to warrant their use in close quarters.

Insofar as prognosis is concerned, most significant is the amount of existing interference with cord function and whether it is of long duration and permanent or the result of an acute episode and reversible.

SUMMARY

Four patients with disabling symptoms caused by herniated thoracic intervertebral discs are presented. The clinical syndrome is reviewed and the literature on the subject is summarized in an effort to establish the condition as a more easily recognizable clinical entity. The poor results previously noted after surgery can be avoided if the diagnosis is made before irreparable spinal cord injury has occurred. Radicular pain caused by irritation of thoracic nerve roots may mimic closely abdominal pain of visceral origin, intercostal neuralgia, pleurodynia and angina. Since the laterally lying disc does not involve the spinal cord early in its course, central nervous system disease is rarely suspected in the differential diagnosis. Despite the fact that diagnostic studies such as pyelography, gastro-intestinal series and others prove to be negative, unnecessary abdominal and thoracic exploratory operations are performed. This occurred in 2 of the patients presented and was narrowly avoided in a third. When the spinal cord becomes involved, either by compression or by interference with its blood supply, surgical decompression is mandatory. Spinal fluid studies and even roentgenograms of the spine may reveal no abnormalities. However, myelography is diagnostic when properly performed, thereby enabling the surgeon to operate with distinct advantage. Recent reports and the results of surgery in the present group of patients indicate that if the diagnosis is established early when minimal radicular and cord damage exists, the prognosis is much more hopeful.

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THE TREATMENT OF SPASTIC PARAPLEGIA BY SELECTIVE SPINAL CORDECTOMY

COLLIN S. MacCARTY, M.D.

Section of Neurologic Surgery, Mayo Clinic and Mayo Foundation, Rochester, Minnesota*

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ANY method of surgery that can be utilized to improve the physical state of a spastic paraplegic person is worthy of description. It is the purpose of this communication to describe a technic that can be used on certain paraplegics and has certain definite physiologic and technical advantages over the more commonly used methods of producing flaccidity. In order to illustrate this surgical approach to the problem, 4 cases will be reported in detail.

If spasticity in flexion or extension exists in the extremities and body distal to the level of injury to the spinal cord, the problem of rehabilitation and general care is markedly enhanced. The spasticity frequently induces such overwhelming situations (for example, urologic complications or bedsores) that death may result. When such situations develop, it then becomes necessary to produce flaccidity in the lower extremities and bladder so that these structures can be adequately cared for. During recent years, the classic methods of producing flaccidity have been by anterior rhizotomy,[13,14] subarachnoid injection of alcohol[4,16] or, more rarely, posterior-column tractotomy.[15] Each method, although it presents its own inherent difficulties, serves a worth-while purpose and each remains a part of the surgeons' armamentarium. An additional procedure, which seems suited to certain conditions, is selective spinal cordectomy. This procedure can be accurately accomplished and, in most instances, expeditiously performed.

The concept of removal of a malfunctioning organ is not new to medicine but in fact is fundamental to the science of surgery. Thus, the gangrenous leg must be removed to save the life of the patient. More recently it has become apparent to neurologic surgeons that patients who suffer from infantile hemiplegias and epilepsy are improved by hemispherectomy.[3,10,17] Physiologically, the "spastic" terminal portion of the spinal cord can be compared to the "spastic epileptogenic hemisphere." In each instance, there are occasions when all or part of the disorganized neurologic structure is best removed from the body.

The idea of removing large segments of the spinal cord first occurred to the author in February, 1948, and on Aug. 31, 1948, a thoracic, lumbar and sacral spinal cordectomy was accomplished in an effort to eradicate a highly

* The Mayo Foundation is a part of the Graduate School of the University of Minnesota.

malignant glioma of the spinal cord. The details and effects of this procedure have been described previously.[11] It became apparent that removal of extensive portions of the spinal cord is compatible with life, but that certain alterations in physiology occur.[12] The most striking effect of spinal-cord removal or extensive injury is catabolic in nature, with manifestations of gynecomastia, hypoproteinemia, decreased metabolic rate, and evidence of demasculinization. Details of this have been recorded previously, and efforts to combat these changes have also been outlined.[5–9] From a practical point of view, it is apparent from this work that the bladder can contract after large segments of the spinal cord have been removed. The evidence indicates, therefore, that spinal cordectomy below the cervical segments is compatible with life, will relieve spasticity, and will produce a flaccid bladder that can contract. Also, intestinal function is little altered when a transected spinal cord is converted to a resected spinal cord.

The effect of spinal cordectomy on sexual function in either men or women is not known. One would suspect, however, that the effect would be no different from what is seen with a cauda-equina type of lesion or after either extensive anterior rhizotomy or subarachnoid injection of alcohol. For a review of this subject the reader is referred to the work of Bors and coworkers.[1,2]

REPORT OF CASES

Case 1. A white woman aged 48 years sustained an injury to the thoracic part of the spinal cord on June 23, 1951, in an automobile accident. Laminectomy on June 26, 1951, revealed trauma of the cord from the 3rd to the 5th thoracic segments inclusive. Spasticity in flexion and the usual mass reflex phenomena gradually developed. An automatic bladder did not develop and a retention catheter was necessary. Bedsores, thrombophlebitis and debilitation became an almost overwhelming problem. Rehabilitation was impossible.

On July 23, 1952, a lower spinal cordectomy was performed (Fig. 1). The spinal cord was removed from the 11th thoracic segment through the conus and upper part of the cauda equina. This resulted in flaccidity of the lower part of the abdominal wall and the lower extremities. Rehabilitation was rapid and well managed. Bedsores were healed by numerous plastic procedures.

The patient has subsequently lived at home. She has continued to require the use of a catheter. This has been employed for convenience, and no attempts have been made to remove it because of the patient's reluctance and inability to become sufficiently mobile to establish satisfactory control of the bladder either with or without transurethral resection. She has become too obese.

The portion of spinal cord from the site of injury (3rd, 4th and 6th thoracic segments) to and including the 10th thoracic segment was left intact to maintain reflex spasticity of this portion of the body, particularly the upper part of the abdominal wall. It was hoped that the intra-abdominal pressure could be reflexly increased to aid in evacuation of the bladder. In this instance, however, it has not been possible to attain satisfactory management of the bladder.

Case 2. A 13-year-old girl fell from her bicycle on Aug. 27, 1952, sustaining immediate paralysis of the lower portion of her body and legs. On Sept. 3, 1952, a

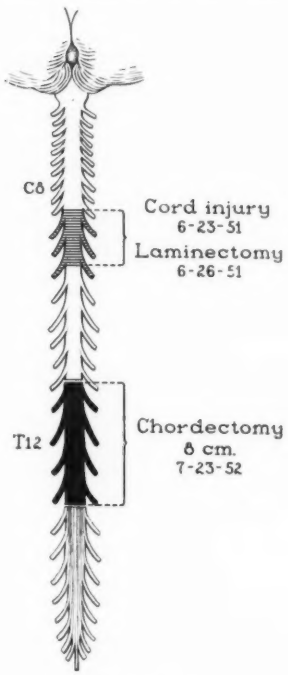

FIG. 1. *Case 1.*

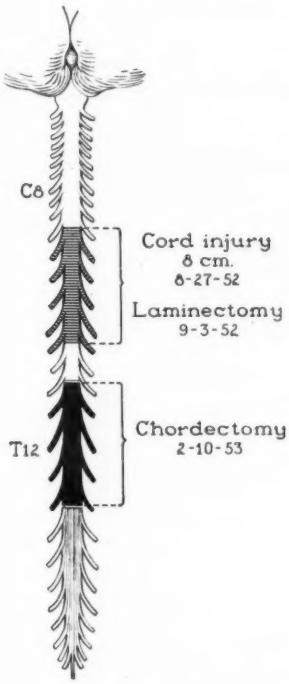

FIG. 2. *Case 2.*

thoracic laminectomy disclosed that the spinal cord was transected and separated for a distance of 1.25 cm. and destroyed for at least 8 cm. in the region of the 5th to 8th thoracic levels inclusive. While the patient was immediately flaccid following injury, she gradually became spastic in flexion and did not obtain an automatic bladder. Bedsores did not become a problem owing to good nursing care and metabolic balance. An indwelling catheter was necessary.

Elimination of spasticity was desired as was an automatic bladder without residual urine. It was felt that selective cordectomy would be the easiest and most accurate way to maintain reflexly intact that portion of the spinal cord represented by the 9th and 10th thoracic segments, and at the same time to create flaccidity of the bladder and lower extremities. With an area of abdominal wall able to contract reflexly it was felt that emptying of the bladder would be facilitated.

On Feb. 10, 1953, the spinal cord was removed from the 11th thoracic segment through the conus and upper part of the cauda equina (Fig. 2). Flaccidity of the bladder and lower extremities and reflex activity in the upper abdominal muscles were realized. The bladder could not empty when the catheter was removed. When the patient underwent cystoscopy on March 11, 1953, by Dr. T. L. Pool, it was noted that "the bladder automatically emptied itself around the cystoscope at periodical intervals. . . . Sixteen bites of tissue were removed from all around the circumference of the vesical neck. She should be able to void." On March 26, she

voided once, and within a few days was emptying her bladder without residual.

Adjustment to postural hypotension was rapid. Elastic bandages were beneficial in this regard. By May 1, she had made good progress in rehabilitation, though stress and strain caused leakage of urine and occasionally incontinence of the bowel. Braces had been applied and by this time she was "able to walk considerable distance, to get in and out of all types of chairs, climb stairs, get in and out of car, dress herself largely," and was allowed to return home. At the time of this writing she is in school. She empties her bladder by manual pressure every 3 hours. In the light of the circumstances of Case 3 to follow, one wonders if resection of the vesical neck is necessary in all women who have undergone cordectomy.

Case 3.—A 49-year-old white woman was admitted to the Mayo Clinic on July 3, 1953. On April 10, 1952, she had sustained a midthoracic spinal-cord injury in an automobile accident. There was immediate paralysis and sensory loss. Laminectomy done elsewhere on April 11, 1952, revealed the spinal cord to be "badly contused." She was dismissed from the hospital on May 17, 1952, and subsequently decubitus ulcers became intractable. There was no neurologic recovery. From June, 1952, to February, 1953, she received daily subcutaneous injections of pyromen. Septic fever developed and chlortetracycline (aureomycin) was administered from February to March, 1953, without any response. From March until June, chloramphenicol therapy was given. The fever subsided only to return as soon as use of the drug was discontinued.

The patient was admitted to the Mayo Clinic in a seriously debilitated condition. Pain in the upper part of the thorax was a major complaint, in addition to paralysis and open septic wounds over the sacrum and hips.

Neurologic examination revealed complete transection of the spinal cord clinically at the level of the 7th thoracic segment. The patient was spastic with her legs in the flexed position. She required continuous catheter drainage and her urinary tract was infected. She was febrile and anemic, and her condition was considered serious.

Roentgenograms of the spinal column revealed a fracture of the 7th and 8th thoracic vertebrae with lateral dislocation of the 7th on the 8th. There were fractures of the ramus of the left ischium, a badly deformed pubic symphysis, and a fracture of the right ischial ramus near the acetabulum. There was complete disorganization of the right hip joint with extensive resorption of the femoral head and neck as well as the acetabulum.

Because of the neurologic picture of "paraplegia in flexion," satisfactory nursing care was impossible. The infected sores would not heal, osteomyelitis of the right femur would not subside, pain could not be controlled, and the infection of the bladder could not be relieved satisfactorily. The problem from this aspect resolved itself into controlling pain if possible and producing flaccidity of the paralyzed parts, presumably including the bladder. Removal of that portion of the cord extending from just above the lesion through the conus seemed to offer a good method of accomplishing this purpose. It was felt that the level of pain (5th and 6th thoracic segments) was too high for a standard cordotomy, and a bilateral cervical or mesencephalic cordotomy was considered to be too risky.

Subarachnoid injection of alcohol or anterior rhizotomy might have been utilized, yet neither of these would alleviate pain in the upper thoracic region. Prefrontal lobotomy for this type of pain is often considered useless. An upper thoracic cor-

dectomy together with a lower cordectomy as in Case 2 might have been considered, but such was not performed in this instance. Before any destructive operation on the spinal cord (cordectomy) was undertaken, the primary lesion was inspected.

On July 14, 1953, the site of the previous laminectomy was opened and the irreparably damaged thoracic cord was observed. Then a cordectomy involving the cord from the 5th thoracic segment through the conus and upper part of the cauda equina was accomplished (Fig. 3). The excised portion of the cord was 21 cm. long.

The desired result was obtained except for persistent annoying girdle sensation and occasional root pain at the upper level of anesthesia (5th thoracic segment). The administration of narcotics was discontinued and a prolonged period of orthopedic treatment was begun by Dr. M. B. Coventry. This included excision of decubitus ulcers and removal of the structures that make up the right hip joint. The wounds healed well and on Dec. 12, 1953, Dr. Coventry completed his care of the patient.

The catheter was removed and the bladder was emptied by pressure over the lower part of the abdomen. On December 21, it was noted that when the patient was on her back, her bladder emptied well; "however, while lying on her face she becomes incontinent." She was rehabilitated to the point of handling a wheel chair, but no effort was made to get her up to walk with crutches or braces because of the complicating orthopedic problems. She was dismissed from our care on Jan. 4, 1954, without a bedsore or the necessity of using a catheter, and with no appreciable residual urine. She seemed well on her way to satisfactory adjustment.

Case 4. A 29-year-old housewife was admitted to the Mayo Clinic on Aug. 26, 1953. In 1941, at the age of 17 years, she had sustained a fracture of the 12th thoracic vertebra in an automobile accident. Complete paraplegia existed from that date. Laminectomy was performed elsewhere following the injury. Recovery of neurologic function did not occur and an indwelling catheter was utilized. The patient visited the clinic in November, 1947, seeking relief of urinary symptoms. Neurologically she had spasticity of the lower extremity, bilateral Babinski sign, and complete anesthesia caudally from the level of the 11th and 12th thoracic dermatomes. On Nov. 10, 1947, she underwent removal of a vesical calculus, and on November 14, transurethral resection of the vesical neck was performed. One gram of tissue was removed because of approximately 200 cc. of residual urine. On November 26, right pelvionephrolithotomy was performed. On December 19, 3 gm. of tissue was removed from the vesical neck with a subsequently satisfactory result. An automatic bladder developed satisfactorily.

One year prior to admission on Aug. 26, 1953, the patient experienced increased spasticity of the lower extremities, uncontrollable contractions of the bladder, and incontinence. She used demerol to control the spasms which before admission had become unbearable. She had to wear a diaper, and the tissue in the region of the sacrum became macerated.

Examination on admission in 1953 revealed typical spastic paraplegia, more pronounced than on the patient's previous visit. Anterior rhizotomy, injection of alcohol into the subarachnoid space, or limited cordectomy was proposed. The patient desired assurance that the cord was irreparably damaged even though the lesion was 12 years old. It was decided therefore to inspect the site of injury and then perhaps perform a limited lower spinal cordectomy. Because pain was not a problem and the abdominal musculature was good, it was decided not to resect above the level of the lesion.

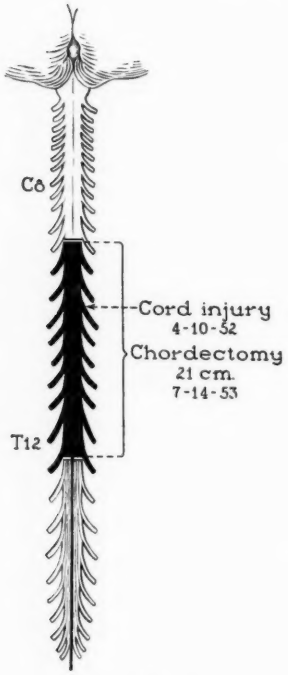

FIG. 3. *Case 3.*

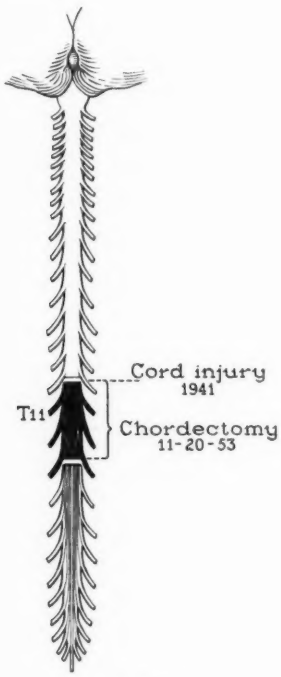

FIG. 4. *Case 4.*

On Nov. 20, 1953, the destroyed segment of cord was identified at the site of fracture. The conus and spinal cord were removed up to and including the scar (Fig. 4). This amounted to 8 cm. of cord.

Flaccidity of the legs and bladder was accomplished. The catheter was removed on Nov. 29, 1953. The amount of residual urine gradually decreased to approximately 30 cc. She could void by straining but occasionally "loses urine at times." It was felt that her urinary status would improve even more with training. She was dismissed on Dec. 6, 1953.

The patient and her physician husband wrote on March 21, 1954, that they were happy with the results of the operation. She stated that "by means of tightening the lower abdominal muscles and straining I literally squeeze the bladder dry. Residual checks after these voidings have revealed a very small amount of urine left in the bladder—5 to 10 cc." She empties the bladder every 3 hours. Its capacity has not exceeded 250 cc. yet.

SUMMARY AND CONCLUSIONS

This paper presents another method of producing flaccidity of the lower extremities to supplement the care of patients with spastic paraplegia. Selective spinal cordectomy is proposed for removal of segments of the spinal cord for this purpose. This concept of removing a portion or all of the mal-

functioning part of the spinal cord is likened to removal of an atrophic cerebral hemisphere in patients suffering from infantile hemiplegia and uncontrolled convulsions. The selectivity of the procedure is stressed. In high thoracic-cord injuries, it is suggested that an isolated segment be left in place to maintain reflex abdominal tone in the hope of improving urinary evacuation. In low thoracic-cord injuries, the lumbar and sacral portions of the cord can be accurately removed.

The first spinal cordectomy by the author was performed for the purpose of removing a glioma of the cord in a patient with spastic paraplegia. The present communication deals with 4 patients who sustained trauma of the spinal cord with resultant paraplegia and spasticity. The management of these patients by removal of segments of the spinal cord distal to the injuries is presented in detail.

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THE SYNDROME OF ACUTE CENTRAL CERVICAL SPINAL CORD INJURY

WITH SPECIAL REFERENCE TO THE MECHANISMS INVOLVED IN HYPEREXTENSION INJURIES OF CERVICAL SPINE*

RICHARD C. SCHNEIDER, M.D., GLENN CHERRY, M.D.,† AND HENRY PANTEK, M.S.E. (EE)

University of Michigan Hospital and Medical School, Ann Arbor, Michigan

(Received for publication July 26, 1954)

IN ACUTE cervical spinal cord injuries, there is a syndrome that suggests central cervical spinal cord involvement. It is characterized by disproportionately more motor impairment of the upper than of the lower extremities, bladder dysfunction, usually urinary retention, and varying degrees of sensory loss below the level of the lesion. If the findings are caused by central cord destruction with bleeding, hematomyelia, there may be caudad or cephalad extension of the lesion with further progression of symptoms, perhaps culminating in complete tetraplegia or death. But if the symptoms are caused by concussion or contusion, with an edematous type of central cord involvement, there may be gradual return of function in a definite sequence. The amount of recovery depends on the degree of edema present compared to the extent of hematomyelia. The lower extremities tend to recover motor power first, bladder function returns next, and finally strength in the upper extremities reappears, with the finer finger movements coming back last. The varying degrees of sensory impairment do not follow any set pattern of recovery.

The syndrome of acute central cervical spinal cord injury occurs most frequently in severe hyperextension injuries which cause a simultaneous squeezing or pinching of the spinal cord both anteriorly and posteriorly. This may occur without apparent damage to the bony spine, having been caused by an inward bulge of the ligamentum flavum during hyperextension. A hyperextension injury of the cervical spine may be suspected when a history is elicited of the patient having fallen foward on his face, or if, on examination, contusions and lacerations are found on the face or forehead. However, this syndrome also may be associated with cervical arthritis, certain cervical compression fractures, and special types of hyperextension or flexion fracture-dislocations of the cervical spine.

Recognition of the syndrome is important, for the authors believe that it may imply a fairly good prognosis. Surgical decompression of the spinal cord is contraindicated because spontaneous improvement or complete re-

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† 909 Medical Arts Bldg., Dallas, Texas.

covery may occur. Furthermore, operation has actually been known to harm these patients rather than improve them.

This is a preliminary report which does not present all the experimental and pathological material that would be necessary to confirm our theories, but it serves as a foundation for building up further proof.

This symptom complex is not a rare one, but it has been incorrectly designated as hematomyelia by various observers for many years. By definition, bleeding into the cord, or hematomyelia, must necessarily be associated with some degree of destruction of cord substance, and therefore some residual neurological deficit might be anticipated. Since complete recovery has occurred in some of these patients, we must assume that there was primarily extensive cord swelling or edema with little or no permanent cord damage. The designation "acute central cervical cord injury" therefore is all inclusive and more accurate. In reviewing the literature, we have found reports of 6 cases with similar symptoms.

In his 1887 paper, Thorburn[32] reported the following case:

Case I. A 40-year-old patient was admitted to the hospital on Aug. 15, 1885, suffering from the results of a 50-foot fall. There was a contusion with a 4-inch laceration on the right side of the forehead. The patient was not unconscious.

All four limbs were "paralyzed," the arms completely so, but the legs could be moved in bed. There was complete anesthesia of the trunk and all four extremities with loss of control of bladder and rectum.

On August 17, the lower extremities moved very readily, but the arms remained immobile. Sensation improved. By August 18, the arms and fingers recovered motor power, and on October 12, the patient was first able to walk. Five months after the accident, he returned to work. There was a residual tingling in his fingers and a sensation of constriction about his abdomen. However, there was no diminution in motor power. The patellar and Achilles reflexes were exaggerated.

Our Comment. We believe that this patient sustained a direct facial impact which resulted in hyperextension of the cervical spine and the acute central cervical cord injury syndrome. Recovery followed the routine pattern described above.

Minor, as cited by Marty,[20] presented a case of "central hematomyelia."

Case II. A 30-year-old peasant was thrown forward from a height of 3 meters, struck the ground, and lost consciousness for an hour. On recovering his senses he could not move his arms or legs. There was pain in the cervical area and in the upper extremities.

No contusion or luxation of the cervical spinal column was observed. There was marked motor impairment in the upper extremities with less in the left leg and only minimal paresis in the right leg. No increased tonus was found in the lower extremities. The patellar reflexes were hyperactive. Touch was preserved over the entire body. An area of analgesia began at the groin and extended along the right side, being more marked in the right leg and extending to T10 anteriorly and the tip of the scapula posteriorly. Apparently there was a complete loss of temperature sensation.

Two months later the patient was notably stronger in all extremities, and was able to stand with difficulty. His patellar reflexes were hyperactive. Pain and tem-

perature could be identified. Five days after this the patient began to walk and soon left the hospital.

Minor observed that there had been acute injury of the cord caused by the fall and that there was no evidence of any bony damage. Two months after the injury there was almost complete recovery except for weakness and atrophy in the hands and exaggerated patellar reflexes.

Our Comment. The fact that the patient was thrown forward and was unconscious for a period of an hour suggests that he struck upon his face and could have had a hyperextension type of injury. Since he had a complete loss of motor power in the upper extremities and only paresis in the lower extremities a central cord type of injury may be postulated. It was definitely stated that there was no evidence of injury to the bony spine and apparently the patient recovered sufficiently so that he was able to walk out of the hospital.

The following case was presented by Spiller:[28]

Case III. A 46-year-old man who fell 8 feet out of a window, struck the ground directly upon his face. On regaining consciousness there was impairment of motor power in the lower extremities. Knee jerks were present and there were equivocal extensor plantar reflexes. There was marked loss of motor power in the upper arms with complete paralysis of the fingers. Touch was normal over the entire body. Pain and temperature sense were markedly diminished over the lower extremities and trunk, but there was not as pronounced a loss in the upper extremities.

By the 14th day after the accident, restoration of movement in the lower extremities was remarkable. On the 30th day there were feeble extensor and flexor movements of each hand. The patient died on the 38th day after the accident.

A "traumatic myelitis" was found which Spiller defined as a degeneration affecting the nerve cell bodies and the nerve fibers, together with a round cell infiltration, proliferation of neuroglia, congestion of blood vessels and miliary hemorrhage. This affected the 4th, 5th and 6th cervical segments.

Our Comment. This was undoubtedly a cervical hyperextension injury since the patient fell upon his face. Recovery was in the usual sequence for central cord damage, i.e., lower extremities, then upper extremities, with the fingers recovering last. One might have prognosticated that recovery would have been fairly good because the impairment of pain and temperature was not so great in the upper extremities, suggesting that the injury had not extended completely to the anterior surface of the cord.

Bufe,[8] published an article on isolated injuries of the cervical spine with no distortion of the bony portion but special observations on hematomyelia. Since these cases fit so completely into our discussion, they will be briefly summarized.

Case IV. On Sept. 19, 1936, a 50-year-old farmer fell headlong from a haywagon. He was not rendered unconscious. His symptoms had improved markedly by the next day, for the complete paralysis of the upper and lower extremities that he had exhibited initially had partially disappeared.

On Sept. 21, 1936, bronchitis developed. A disturbance in sensation and motor

power was found from C4 level on downward. Both patellar and Achilles reflexes had completely returned. There were positive extensor plantar signs. The bladder was completely paralyzed. Roentgenograms of the cervical spine revealed no fracture. Four days after the accident, the patient succumbed. A summary made at the time of death suggested that both the original motor and the sensory impairment had regressed considerably but the exact extent was not listed.

At autopsy there was central softening from the region of C4 through T3 spinal segments. No abnormality of the bony spine was found.

Case V. On Aug. 20, 1936, a 66-year-old man fell head first downstairs, and was not rendered unconscious. He was unable to rise from the floor and could not move his arms. There was a 2-cm. laceration of his forehead.

Pain was produced on percussion over C4 through C7 spinous processes. Movement of all four extremities was completely abolished. There was hypesthesia over the upper extremities with a disturbance of heat and cold. (The exact extent was not mentioned.) Abdominal reflexes were readily elicited but cremasteric reflexes were absent. The Achilles and patellar reflexes were retained. There were no extensor plantar reflexes. Paralysis of the bladder and rectum was present. Cervical roentgenograms showed no evidence of any fracture.

On the day after injury the previously spastic upper extremities became more flaccid. Five days after the injury the patient died of bronchopneumonia.

At autopsy there was no evidence of any fracture. A tubular central hemorrhage of the cord was found between C4 and C7 segments.

Case VI. A 52-year-old landlord became drunk and fell downstairs. He sustained immediate pain in his back , and was unable to move his arms and legs.

On arrival at the hospital there were no external signs of injury. There were no extensor plantar reflexes. The patellar and Achilles reflexes were active and were definitely stronger on the right side. Hypesthesia was noted at the level of the wrists. There was pain and temperature disturbance in the lower extremities. Total paralysis was found in both arms and the left leg. The right leg could be bent at the knee and the toes could be moved. There was complete bladder paralysis. X-rays of the cervical spine revealed no evidence of any injury.

Halter traction was applied. On the 4th day post-injury there was spontaneous recovery of his bladder and his original flaccid paralysis became spastic. After 8 days the movements in his arms and legs improved. Leg spasms almost completely disappeared. A few weeks after injury, the mobility of the lower extremities was markedly improved, but only minimal finger movement was found. Sensation was unaltered. After 2 months he was able to perform exercises with his arms and legs. The patient was hospitalized for 9 months, but the final clinical result was not reported.

Our Comment. In reviewing these 3 cases it should be noted that each of these patients apparently fell head first. They were all above 50 years of age and although no note was made about any possible arthritic spurring of the cervical vertebra, it certainly could have been present. The neurological examinations were far from adequate but in 2 instances there was a definite history that the arms were completely paralyzed with paralysis of the bladder and preserved reflexes or minimal movement in the legs. In 1 of the cases, recovery was in the routine manner of lower extremities first, bladder return

next and upper extremity last. In the 2 cases in which autopsy was performed, central cord damage was found over a distance of at least 3 to 5 or 6 segments.

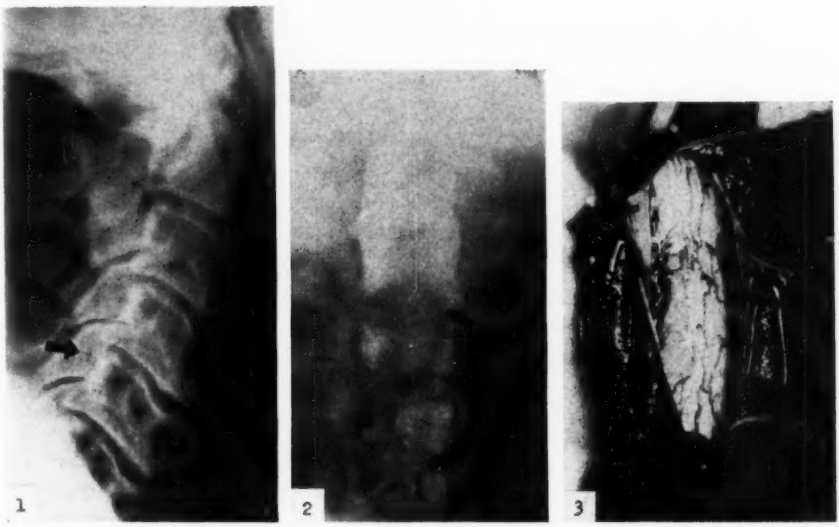
Perardi[22] presented in detail a case of hematomyelia following facial trauma. This spinal lesion was located about the central canal in the thoracic region without any evidence of fracture to the bony spine, suggesting that the same pattern of central cord injury had occurred as had been found in the cervical region on hyperextension of the cervical spine. It must be admitted that the point of injury, T4, was a very unusual one at which to expect hyperextension because of fixation of the spine at this level by the thoracic cage. The paper is important, however, in that Perardi apparently was the first to note the importance of facial trauma in cases of hematomyelia. He did not enlarge upon the mechanisms involved in this type of a lesion. Later Taylor and Blackwood[31] emphasized that facial injury suggested the presence of a hyperextension cervical injury.

We would like to present 8 patients (Cases 1–8) who exhibited different degrees of the acute central cervical spinal cord injury syndrome. In Case 4 the central cord damage was sufficiently low in the cervical area so that the neural segments for finger movement were not involved, and the syndrome was not complete. A ninth patient (Case 9) with marked comminution and fracture-dislocation of the cervical spine is included to demonstrate the most severe type of cervical hyperextension injury in which immediate complete tetraplegia occurred and progressive hematomyelia was responsible for the patient's death. The range of injury in these cases, therefore, runs from simple cervical spinal cord concussion with recovery, to complete destruction and death. (To avoid confusion with the cases abstracted from the literature, our own case reports have been designated by arabic numerals.)

Case 1. On May 31, 1952, H.R., a 65-year-old man, tripped on a rug and fell directly forward on his face, striking his forehead on the floor. After being comatose for an indefinite period of time, he regained consciousness to discover that he was numb and paralyzed in all four extremities. He stated that most of his numbness vanished after a period of 4 days, and that he had regained some degree of motor power in both legs, but with much less movement in both arms. He had been unable to void and had to be catheterized.

He was admitted to University Hospital on June 5, 1952. Motion and position sense were intact, vibratory sensation was only spottily preserved, being absent over the lower extremities but present over the upper. However, two-point tactile sensation was completely lost. There was a level of hypalgesia and hypesthesia to C7 dermatome bilaterally, and a level of thermanesthesia to T1 dermatome bilaterally. Paresis was present in both lower extremities, but was much more pronounced in all movements of the upper extremities. There was a marked increase in tonus of all four extremities. Deep reflexes were equal and active with symmetrical hyperactivity of the patellar reflexes. There were positive extensor plantar reflexes. Cervical spine roentgenograms revealed no evidence of fracture or fracture-dislocation, although it was difficult to secure good visualization of the C7 vertebra. Marked hypertrophic spurs were noted projecting posteriorly into the spinal canal at the

C4–C5 interspace (Fig. 1). A lumbar puncture was performed with no evidence of any subarachnoid block on manometric testing. A cervical myelogram revealed a filling defect in the midline of C4–C5 interspace (Fig. 2).



FIGS. 1–3. *Case 1.* (1) Lateral roentgenogram of cervical spine. Arrow indicates the posterior spurring of C4 and C5 vertebral bodies. (2) Myelogram demonstrating almost complete block at C4–C5 interspace. (3) Operative field showing site of constriction of spinal cord at C4–C5 interspace.

Cervical laminectomy was performed on June 10, 1952, with removal of the laminae of C4, C5 and C6 vertebrae. A dural incision was made in the midline and the dentate ligaments were sectioned at three levels. There was considerable arachnoiditis at the level of C4. At all of the exposed interspaces, moderate hypertrophic spurring could be identified by palpating the anterior wall of the vertebral canal transdurally. At the level of C4, C5 on the left side, an unusually large hypertrophic spur was identified by transdural exploration. Approximately 2 or 3 mm. above this hypertrophic spurring there was noticeable constriction of the spinal cord, most marked on the right side. The spinal cord was slightly bluer below this point (Fig. 3). The dura mater was sutured and the wound was closed in layers.

Postoperatively the patient had a complete tetraplegia with a level of hypalgesia at C4 bilaterally. This level had become progressively higher during the 2 days following myelography. Motion and position sense were intact on the left, but absent on the right. Marked extensor spasm was noted in the lower extremities. The reflexes were equal and active bilaterally with hyperactivity of the patellar reflexes and bilateral extensor plantar reflex.

When last seen on July 7, 1952, his status was unchanged. He was sent to a nursing home where his condition gradually deteriorated, and he died on Sept. 12, 1952 of chronic myocarditis with cardiac decompensation. Unfortunately no postmortem examination was performed.

Comment. The above patient had a severe hyperextension injury of the cervical spine without fracture or dislocation of the vertebra (Fig. 4). Although neurological findings were not known immediately after injury, the patient gave a history of numbness of his entire body, as well as tetraplegia following his accident. Apparently the numbness lasted for a period of 4 days.

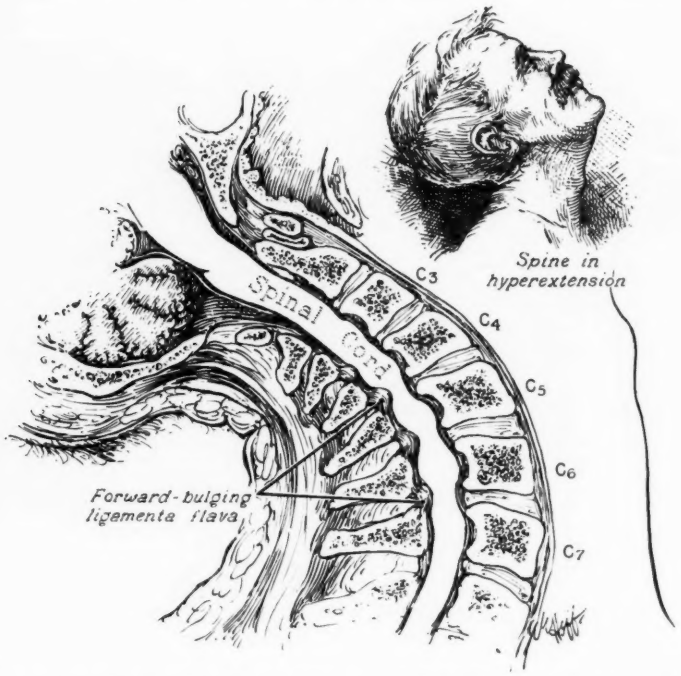


FIG. 4. *Case 1.* Drawing illustrating the impingement of the ligamentum flavum on the posterior aspect of the spinal cord. Anteriorly counter pressure is exerted by the hypertrophic spurs on the vertebral bodies.

There is no doubt in the authors' minds that this patient was further injured by operation. The centrally damaged cervical spinal cord described above was probably further compromised by pressure on the lateral surface of the cord over the lateral corticospinal tracts when the dentate ligaments were sectioned or there could have been delayed softening of the cord. As a result the remainder of the initially functioning motor fibers in the lower extremity which lie most laterally were irreparably damaged, resulting in complete postoperative tetraplegia. Pial incision or myelotomy could have caused more damage in the face of constriction of the cord and the crowding of the blood vessels on the cord's dorsal surface.

Case 2. M.N., a 61-year-old woman, was involved in an automobile accident at 7:15 P.M., on Dec. 12, 1952. The car in which she was riding was struck broadside at an intersection and was overturned. The patient struck her frontal region on the windshield or dashboard with immediate paralysis of the arms and lower extremities, and numbness from the neck downward.

Upon examination the patient was found to have a 3-cm. midline laceration of the forehead. Breathing was purely diaphragmatic. The vital signs were normal. No cranial nerve abnormality was noted. There was no movement in the upper extremities. In the lower extremities the only motor power was feeble internal rotation at both hip joints. There was a loss of all sensory modalities, including superficial and deep pain, touch, motion, position sense, and temperature sensation below the level of the C4 dermatome. There was a complete areflexia in the upper extremities but the patellar and ankle reflexes were equal and active. The abdominal reflexes were symmetrically hypoactive. There were positive extensor plantar reflexes. Mass withdrawal movements could be demonstrated bilaterally. Urinary retention was present.

FIG. 5. *Case 2.* Lateral cervical roentgenogram showing the congenital fusion of C2 vertebra with C3. Arrow demonstrates hypertrophic spurring of C3 vertebral body. Calcium deposits may be seen anterior to the vertebral bodies.

Roentgenograms of the cervical spine demonstrated a congenital fusion of C2 vertebra with C3 with posterior spurring of the inferior margin of that vertebra and some calcification in the anterior ligament of C2–C3, C5–C6, and C6–C7 interspaces (Fig. 5).

Crutchfield tongs were inserted in order to maintain the head in a stable neutral position. On the day after admission the patient was able to perceive and localize deep pain in the feet, and there was spotty return of superficial pain to the level of C5 on the left. Forty-eight hours after injury, paresthesias were felt over the entire body, and the patient could detect the insertion of the catheter in her bladder. A lumbar puncture at this time demonstrated no evidence of blockage of the subarachnoid space on the jugular compression test. The spinal fluid was clear and Pandy test was negative. On the 4th day after injury, there were marked hyperesthesia and paresthesias in the lower extremities. By the 10th day the patient was able to move both lower extremities, the left better than the right.

On Jan. 14, 1952, the patient still could not discern motion or position or vibration sense. There was a loss to cold bilaterally and cold felt unpleasantly hot on the

right side of the body. Light, non-discriminatory touch could be noted over the entire body. No voluntary movements were observed in the upper extremities, but lower extremities could be moved voluntarily. There was symmetrical hyperactivity of the deep reflexes of both upper and lower extremities with a positive Hoffmann test on the left and an equivocal one on the right and a positive right extensor plantar reflex.

Laminectomy of C3, C4 and C5 was performed. There was marked instability at the C3–C4 interspace. No fractures or hematoma could be demonstrated. The dura mater was opened in the midline and the dentate ligaments were cut at three levels. The spinal cord was normal in appearance, and upon exploring transdurally at the C3 vertebral body the presence of a bony spur was confirmed. The wound was closed in layers.

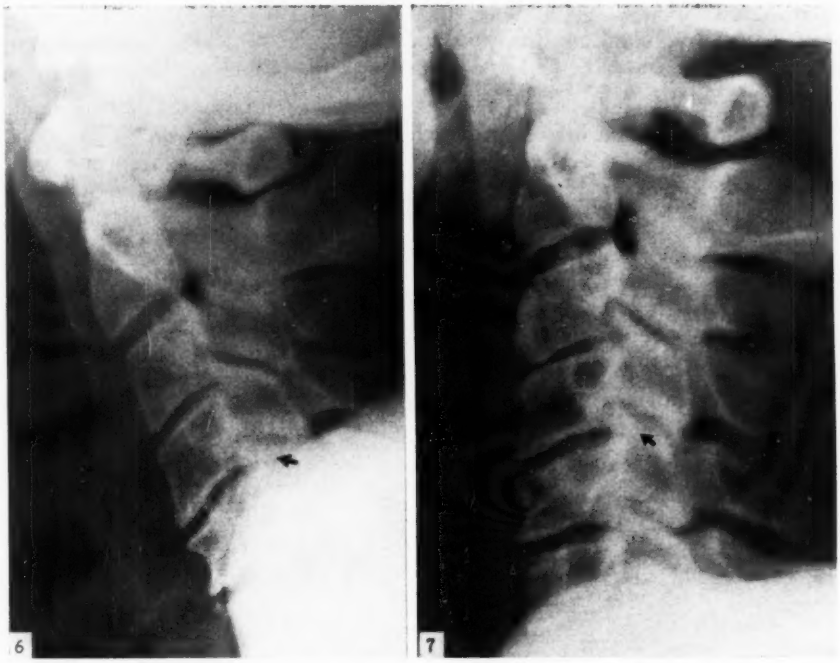
The patient continued to improve so that at the time of discharge she had good movement in all muscle groups in the lower extremities and in the arms and forearms. There was good hyperextension at the wrist, but there was very little finger movement. She was transferred to a convalescent home, where she expired on May 30, 1953. The cause of death was believed to be hypostatic pneumonia. No postmortem examination was obtained.

Comment. This patient sustained a typical acute central cervical spinal cord injury without any evidence of bony involvement. The bony spur at C3–C4 interspace encroached upon the anterior surface of the spinal cord and the acute hyperextension of the cervical spine caused inward bulging of the ligamentum flavum with pressure upon the posterior surface of the spinal cord. The patient's recovery was in the routine sequence, namely, the lower extremities had return of function first, bladder recovery was next, and finally the upper extremities were regaining movement at the time of her discharge. The fact that the patient's fingers had not shown recovery of movement indicates that the fibers innervating these structures lie most medially in the lateral corticospinal tract. It is also evident that the fiber tracts in the ventral white matter of the cord recovered earlier than the paths in the posterior columns. This is illustrated by the early return of both deep and superficial pain and visceral sensation from the bladder within 48 hours after injury. We feel that operation neither hindered nor helped this patient.

Case 3. H.K., a 57-year-old man, was rendered transiently unconscious in an automobile accident on June 5, 1953, and was taken to a hospital. Upon arrival there at 3 P.M. the patient had no recollection of the accident.

There was a tender contusion-laceration over the right temporal region. There was complete sensory and motor impairment from the neck downward. Breathing was diaphragmatic. At 5 P.M. the patient moved his foot and legs minimally on painful plantar stimulation.

Skull roentgenograms showed a fracture of the tip of the nasal bone. There was some evidence of posterior arthritic spurring of the C3, C4 and C5 vertebral bodies (Fig. 6). Films of the cervical spine showed no fracture or dislocation; but chest x-rays demonstrated an elevation of the left hemidiaphragm. Lumbar puncture performed shortly after admission showed a pressure of 210 mm. of water with a prompt rise on bilateral jugular compression to 320 mm. and a rapid drop to the original level. The puncture was atraumatic. Nevertheless, the first specimen showed a



FIGS. 6–7. *Case 3.* (6) Lateral roentgenogram at time of injury showing hypertrophic spurring at C4–C5 interspace (arrow). Note prevertebral hematoma or edema. (7) Lateral roentgenogram 6 months after injury. Note increased arthritic changes with calcification in anterior longitudinal ligament.

crystal-clear spinal fluid, the second was blood-tinged and the third quite bloody.

By June 7, 1953, no sensory deficit was demonstrable; the biceps reflex was weakly positive bilaterally, but triceps was not elicited. On that day suprapubic cystotomy was performed. By June 9, it was observed that he could move his right lower extremity, but no motion was found in the other three extremities. By the following day there was some motion in the left foot.

At the time of transfer to another institution on June 17, 1953, there was good movement of the shoulder girdle, and minimal action in the hamstring muscles and the feet. The latter was more marked on the right side. A band of hypalgesia was found on the right side from a mid-portion of the back downward over the right lower extremity and foot. Areflexia was present in the upper extremities, but there was symmetrical hyperreflexia of both patellar and Achilles reflexes without patellar or ankle clonus. Positive extensor plantar reflexes were found.

Examination on Jan. 22, 1954 demonstrated fair motor power in both lower extremities with fairly marked spasticity and bilateral extensor plantar reflex. Motor power was good in the shoulders and the upper arms, but flexion and extension at the wrist and finger movements were absent. There was marked periarthritis of the joints in the hands. Only a zone of L3 hypalgesia persisted in the right lower extremity. Recheck roentgenograms at this time demonstrated increased vertebral

spurring with projection into the cervical spinal canal at C4–C5 and C5–C6 interspaces (Fig. 7). A chest x-ray showed residual elevation of the left hemidiaphragm (Fig. 8).

Comment. This patient had a blow to the right temporal region which had caused contrecoup left lateral hyperextension of the cervical spine. The arthritic spurring at C4–C5 interspace was sufficient to cause anterior compression of the spinal cord and probably large enough to catch the main cervical roots contributing to the left phrenic nerve, thus causing paralysis of the left diaphragm. Recovery occurred first in the lower extremities and finally in the shoulders and forearms, but periarthritis 6 months after injury was so severe that it is doubtful whether the fingers could have moved if motor function had been present. Since these digits recover last, it is imperative that they have good early passive motion and massage. Return of bladder function could not be evaluated since the patient had a suprapubic cystotomy 2 days after his injury. It was interesting to note that there was only the minimal residual sensory loss in the right L3 dermatome and that most of this sensory recovery apparently occurred as early as the second day after injury.

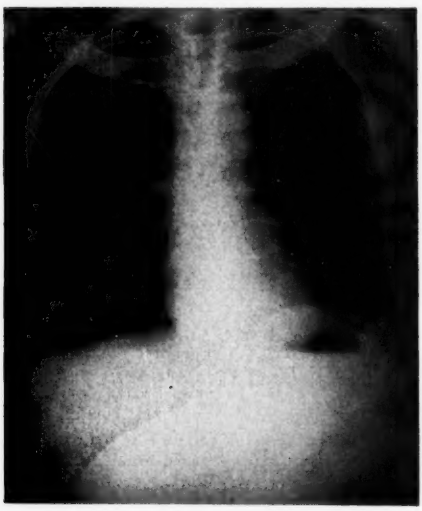


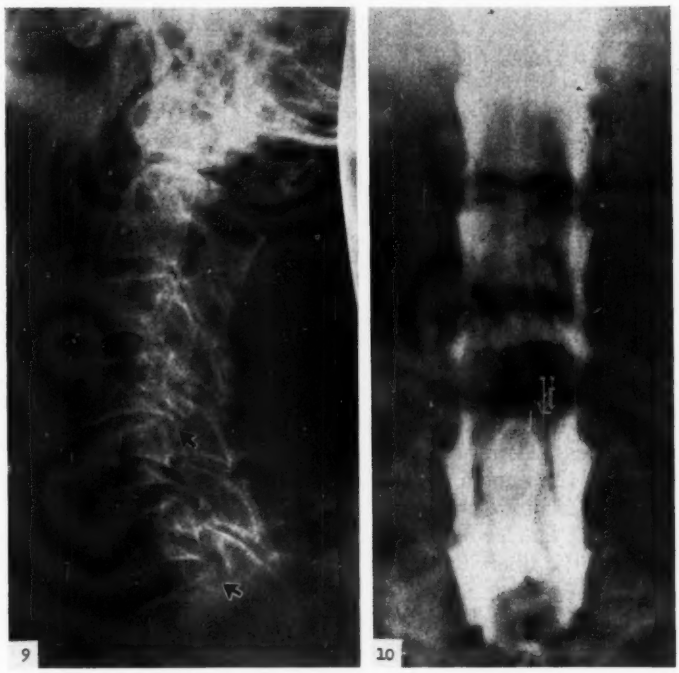
FIG. 8. *Case 3.* Chest roentgenogram 9 months after injury showing elevation of left hemidiaphragm. (Primary right temporal contusion-laceration had occurred with a contrecoup injury to left phrenic nerve.)

Case 4. D.O., an 85-year-old farmer, fell from a 15-foot haymow to the ground on Jan. 7, 1954. His wife found him lying on the floor of the barn, bleeding from lacerations of the face and nose. The patient stated that he had not been unconscious and that he could walk shortly after the fall, but his legs became weak and he had collapsed.

Upon admission to the hospital 4 hours after the injury, he had difficulty with movement of his legs, but on command, moved the right foot. He had motor power in both upper extremities, but had a poor grip in both hands. There was stiffness and soreness of the neck. Hypalgesia was found on the left side of the face and below the clavicles bilaterally, but there was a definite appreciation of pain over the legs and abdomen. The biceps, triceps, abdominal and cremasteric reflexes were equal and active, but deep reflexes of the lower extremities were absent, with no extensor plantar responses.

Cervical spine roentgenograms showed a diminution of the C4–C5 interspace with marked hypertrophic changes on the vertebral bodies at C4–C5 and C6–C7

interspaces (Fig. 9). A lumbar puncture showed no subarachnoid space block but the spinal fluid contained 66 mg. protein per 100 cc. and Pandy test was positive. At the time of cervical myelography the pantopaque became separated at the C6–C7 interspace and was partially deformed to the level of the C3–C4 interspace where it coalesced again. Within these limits there was a suggestion of midline defect (Fig. 10).

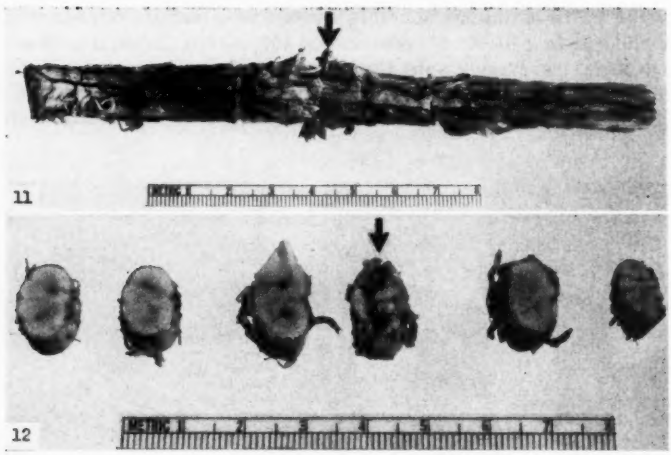


FIGS. 9–10. *Case 4.* (9) Lateral roentgenogram of cervical spine with arrows indicating arthritic spurring at C4–C5 and C6–C7 interspaces. (10) Cervical myelogram demonstrating pantopaque defects at C4–C5, C5–C6 and C6–C7. Myelography should be avoided a) for fear the necessary hyperextension will cause more cord damage and b) the pattern of central damage causes diffuse central swelling and defects over several interspaces.

Gradual impairment of motor power then occurred in the upper extremities and the patient's respirations ceased on Jan. 20, 1954.

Autopsy revealed no evidence of fracture or fracture-dislocation of the cervical spine, but merely the hypertrophic arthritic changes. The point of maximal central damage to the cord appeared to be at the level of the C6–C7 interspace where the lowermost portion of the cervical myelographic defect was noted (Figs. 11–12). Some gross destruction was found above this level with marked microscopic injury.

Comment. This patient probably fell head first from the haymow, as was evident from the multiple lacerations of the face and nose. There was no



FIGS. 11–12. *Case 4.* (11) Posterior view of portion of cervical-thoracic spinal cord showing maximal damage at C6–C7. (12) Cross sections of above cord at various levels. Note central extension of lesion.

demonstrable bony injury, but only the hypertrophic spurring of the vertebral bodies was found. The patient could move his legs initially but gradually had motor loss. There was weakness of the fingers originally, but not the true paralysis of the fingers usually seen in acute central cervical cord damage. The reason is obvious when the specimen is examined, for the lesion probably had not had proximal extension initially into the higher cervical segments where the fibers to the hands could be involved in the pyramidal tracts.

Case 5. M.T., a 42-year-old woman, was involved in an automobile accident at 12:30 P.M. on July 7, 1952, being thrown forward from the front seat to the floor of the car. Immediately following the injury she was unable to move all four extremities and was numb from the neck downward. After being placed in halter traction, she soon was able to move her legs, but still had no motion in her upper extremities until 7 P.M. on the day of injury. There was progressive improvement in strength in all four extremities. There was no bladder or bowel incontinence, and at 5 P.M. on the day of injury she was able to void normally. The patient was transferred to University Hospital.

An examination at 10 P.M. on the day of injury revealed a band of hypalgesia and hypesthesia from C3 to T3 dermatomes bilaterally. No note was made of temperature sensation having been tested. Motion, position and vibration sense were intact throughout. All movements of the lower extremities were normal. In the upper extremities, strength was equal bilaterally, except that there was no dorsiflexion of the right wrist or extension of the fingers of the right hand. Deep reflexes were equal and active except that the right biceps reflex was diminished. There were equivocal extensor plantar reflexes. Roentgenograms of the cervical spine revealed no evidence of fracture or dislocation, but a slight narrowing of the C5–C6 interspace. Halter traction was continued with 10 pounds of weight applied.

On the following morning the band of hypalgesia and hypesthesia previously described had disappeared. There was some increased weakness in the right triceps but the patient could dorsiflex the right wrist and extend the fingers of the right hand. Crutchfield tongs were substituted for the halter traction since the patient was having so much discomfort. A lumbar puncture performed 5 days after injury, on July 22, 1952, revealed a clear colorless fluid under normal pressure with no evidence of a subarachnoid space block upon bilateral jugular vein compression. There were no cells in the fluid and protein was reported as 98 mg. per 100 cc. The Crutchfield tongs were replaced by a Forrester neckbrace on July 28, 1952. At the time of discharge on Aug. 4, 1952, the patient was able to walk about, but displayed some weakness in the grip of the right hand, marked weakness of the right triceps and hypalgesia over the dorsum of the right hand.

Comment. This patient had a severe contusion of the cervical cord without evidence of bony injury. The fact that she was thrown forward from her seat onto the floor of the car as indicated by the history, suggested that she might have sustained a hyperextension injury of the cervical spine. It is possible that there was a direct thrust by the ligamentum flavum against the posterolateral portion of the cord, causing more marked weakness in the arms and in the legs. No etiological factor for counterpressure anterior to the cord could be demonstrated. The band of hypalgesia from C3 to T3 dermatome indicates spinal cord involvement. The fact that motion, position and vibration sense were preserved at the time of examination $10\frac{1}{2}$ hours after injury, may be explained by the fact that the posterior compression was slight and return could have occurred during that brief interval. Lumbar puncture demonstrating no evidence of block or bloody fluid suggested that the elevated spinal fluid protein was probably caused by irritation of the cord, and confirms the belief that there was a severe contusion.

One may speculate as to whether later some degree of gliosis may occur with a chronic development of neurological signs and symptoms. Contusion infers a severe blow to the cord with definite anatomical changes, transient or permanent. Concussion implies a temporary physiological interruption of a less severe degree, and is not associated with irritation or destruction, as is indicated by a normal amount of protein in the spinal fluid.

Case 6. W.M., a 34-year-old male, was bending forward between a wrecker and his car, when he was struck in the neck by a large steel hook hanging from a chain on the wrecking truck. He was projected forward upon his face and was not rendered unconscious. The patient recalls that he could not move his arms or legs immediately, but that upon reaching the hospital a slight amount of movement had returned in the lower extremities. There was immediate pain in the neck, marked weakness and numbness of both arms, with gradual recovery of motor power in both legs. He was unable to void and had to have an indwelling catheter inserted. Halter traction was applied for a period of 4 days at the local hospital, and a plaster jacket was then substituted in order to maintain his head in a neutral position. Cervical spine roentgenograms revealed a compression fracture of the C6 vertebral body with minimal displacement of its posterior inferior margin into the spinal canal (Fig. 13). Five days after injury, the patient was able to void voluntarily.

Upon admission to University Hospital on July 11, 1953, there was pronounced

weakness in the grip bilaterally with especially marked weakness in abduction and adduction of the fingers. Moderate weakness was exhibited in the biceps and triceps muscles bilaterally with some weakness of flexion and extension of the wrist, and pronation and supination of the forearm. There was no weakness in any muscle group of the lower extremities. Hypesthesia, hypalgesia and thermanesthesia were demonstrated over C5 through T2 dermatomes. The greatest loss was found in the region of C7 and T1, where there was an almost complete loss of all sensory modali-

FIG. 13. *Case 6.* Compression fracture of C6 vertebral body with minimal posterior displacement of posterior inferior margin into the spinal canal.

ties. There was no definite sensory loss over the chest, abdomen, lower extremities and saddle area. Motion and position sense were most impaired over the little finger bilaterally, but were well preserved elsewhere. Sensory loss in the C7 and C8 dermatomes included all modalities. Lumbar puncture on July 17, 1953, 11 days after injury, revealed no evidence of any subarachnoid space block. The spinal fluid total protein content was 22 mg. per 100 cc.

The plaster jacket was worn for a period of 3 weeks, and then was replaced by a Forrester collar with a Taylor backbrace. The patient continued to have marked improvement so that at the time of his discharge on Aug. 8, 1953, he was neurologically negative.

Comment. This man had a typical hyperextension injury with a compression fracture of C6 vertebral body and considerable edema about the central canal of the cervical cord. With regression of this edema, his neurological symptoms subsided in the routine manner. The fact that he had sensory involvement over four or five dermatomes, plus the number of muscle groups involved, indicated central cord involvement which was spreading laterally toward the posterior roots at C7, the level of the lesion. The root of C7 was pinched, accounting for loss of motion and position sense. The fibers entering at C8 were probably caught after entering the spinal cord.

Case 7. M.M., a 19-year-old man, was involved in an automobile accident at 11 P.M. Nov. 14, 1952, when he was thrown from his car. He did not know exactly how he struck the ground, but he was never unconscious. He could move both arms at the shoulders, and was able to flex the forearms bilaterally, but could not extend them. He was unable to move his left hand, but had, according to one observer, a very minimal flicker of motion in the index finger and thumb of the right hand. There was no involvement of the lower extremities. There was numbness from the shoulders downward over the entire body.

At a local hospital an indwelling catheter was inserted because of the patient's inability to void, and his physician noted a loss of movement of his left leg, both arms and both hands. On the morning following the accident, he could move both lower extremities and by Nov. 19, 1952 he had regained control of his bladder.

On Nov. 21, 1952 he was admitted to University Hospital, where it was noted that there was a good strength in the biceps muscle bilaterally but that the triceps muscles were paralyzed. Wrist extensors exhibited fair strength bilaterally with more strength on the right side. There was a very weak grip on the right side and no movement in the left hand. Weakness was present in both lower extremities with the left side definitely weaker than the right, but the tonus was normal bilaterally. There was analgesia over the radial aspect of both forearms and hands. Hypalgesia was noted over the forearms up to the C5 dermatome bilaterally. There was dissociated sensory loss over the hypalgesic areas in the arm. Motion sense was normal in both great toes. Deep pain was present on the left, but absent on the right side of the body. There was an absence of the triceps reflex, but the biceps, patellar and Achilles reflexes were equal and active, with negative pyramidal tract signs in the upper extremities and a positive extensor plantar reflex on the left. An equivocal extensor plantar reflex was noted on the right side.

Cervical spine roentgenograms revealed anterior fracture-dislocation of C4 vertebral body on C5, and C5 vertebral body on C6, with a decrease in height of the interspace at C6–C7, and impingement posteriorly on the canal by the laminae (Fig. 14).

Vinke tongs skeletal traction was applied with 30 pounds of weight accomplishing about 90 per cent reduction. On Dec. 1, 1952 definite horizontal nystagmus was observed bilaterally. Examination on Dec. 17, 1952 revealed hypalgesia on the right from C5 through C8, and on the left from C6 through C8. Light touch was present, but diminished over these areas. There was hypalgesia over the right lower extremity with a vague sensory level just above the knee.

On Dec. 17, 1952, spinal fusion was performed from C3 through T1 spinous processes. Postoperative films showed stability and satisfactory alignment. Three months later there was no neurological residual.

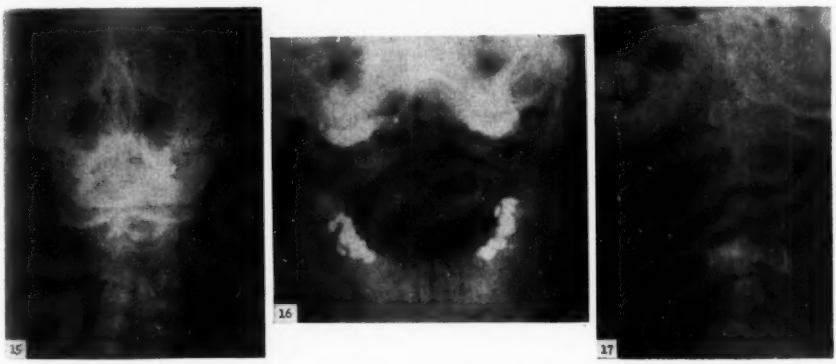
FIG. 14. *Case 7.* Lateral roentgenogram with arrows indicating fracture-dislocation at C4–C5 and C5–C6 interspaces.

Comment. This patient had central cord edema on a different basis from the other cases described above. It is believed that there was a flexion injury with some degree of anterior cord compression by the fracture-dislocation at C4–C5, and C5–C6, with the vertebral body of C5 being displaced posteriorly into the spinal canal. Because of the staircase effect of the multiple fracture-dislocations, it was felt that the laminae at C6 might have caused some degree of posterior counterpressure upon the cord. Central cord compression occurred over a span of several segments. This resulted in edema rather than destruction. The usual pattern of return of function was similar to that noted in the preceding cases of hyperextension.

This case indicates that the lateral spinothalamic tract was more involved on the left than on the right, with extension of the lesion into the most lateral portions of the cuneatus, pyramidal and spinothalamic tracts, sparing the gracilis and cuneatus tracts. It stresses the obliquity of the pattern of segmental arrangement in the posterior columns.

Case 8. R.S., an 18-year-old college student, was involved in an automobile accident at 1:15 A.M. on Oct. 18, 1953. He was thrown from the car when it overturned. Upon regaining consciousness he was unable to move all of his extremities.

On arrival at University Hospital an hour after the accident, examination of the cranial nerves revealed no abnormalities. The biceps muscles were definitely weak. The triceps and all hand muscles were totally paralyzed bilaterally. There was slight motion of the internal rotators and flexors of the left hip, with much less internal rotation in the right hip. All movements of the knees, ankles and toes were absent bilaterally. The patient's breathing was entirely diaphragmatic. There was complete loss of pain and temperature sensation to the C6 dermatome bilaterally. Deep pain sensation could be localized in both legs and arms, but it was very poorly elicited in the right leg. Light touch was partially localized on the left side of the body but was vague on the right. Position sense was poorly localized. There was no



FIGS. 15–17. *Case 8.* (15) Anteroposterior cervical roentgenogram with arrow indicating disruption of the right articular facets. (16) Greenstick fracture of the odontoid process with tilt toward the right side. (17) Lateral cervical roentgenogram demonstrating the fracture of the odontoid process and unilateral fracture-dislocation of C6 vertebral body anteriorly on C5. The latter is apparent from the discrepancy in degree of rotation between the upper and lower portions of the spine.

evidence of a definite sweating level. The biceps reflex was more active on the right than on the left. Triceps, radial-periosteal, knee and ankle reflexes were absent bilaterally. Abdominal and cremasteric reflexes could not be elicited. There were positive extensor plantar reflexes. Priapism was noted. The bladder was atonic and upon catheterization, 300 cc. of urine were obtained.

On the anteroposterior roentgenogram, the pedicles of C4, C5 and C6 seemed to be comminuted on the right side and dislocated, but their counterparts on the left side appeared intact (Fig. 15). Open-mouth roentgenograms of the cervical spine showed a greenstick fracture of the base of the odontoid process, so that a major portion of it was avulsed on the left side, but on the right the process was intact (Fig. 16). On the lateral view this structure seemed to be displaced about 3 mm. posteriorly. There was no significant displacement of C1 on C2. The C4 vertebral body was compressed with slight anterior dislocation on the C5 vertebral body. On the lateral cervical spine roentgenogram a bony spur projected into the canal at C4–C5 and there was a unilateral fracture-dislocation (Fig. 17).

At 4 A.M., Vinke tongs were inserted and 25 pounds of traction were applied. Immediately thereafter there was some improvement in the motor power of the left leg. Nine hours after injury the patient had shown considerable increase in motor power in the hip flexors of the left leg with little change in the right leg. Strength was not increased in the upper extremities. Motion and position sense were now accurately perceived in the left foot. Pressure and touch were much better localized between T3 to L3 dermatomes, but pin prick was absent or poorly localized. Vibration was preserved over both ankles, and the Achilles reflex was now present bilaterally. (Two hours prior to this examination it had been absent.) Positive extensor plantar reflex persisted bilaterally. A lumbar puncture performed 36 hours after injury revealed a normal WBC count and clear spinal fluid with no evidence of any blockage of the subarachnoid space on the jugular compression test.

On Nov. 16, 1953, an iliac bone graft spinal fusion was performed including C2 through C5 spinous processes and laminae without laminectomy and exploration of the spinal cord.

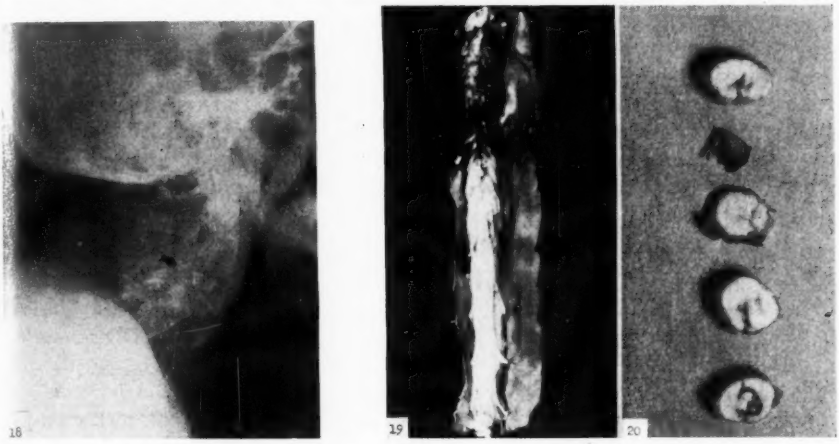
Six months after injury, on Mar. 10, 1954, the patient was able to walk with crutches using all four extremities moderately well except for the finer movements of the right hand which had recovered only 10 per cent of normal function. Strength in the left hand was only 65 per cent of normal. Recovery of motor power in the lower extremities had far surpassed that in the upper ones. There was a level of hypalgesia on the left side of the body to the T2 dermatome. The deep reflexes were symmetrically hyperactive with bilateral extensor plantar reflex.

Comment. This patient showed a typical acute central cervical cord injury. There was a marked contusion over the left frontotemporal area suggesting that the head and the neck were thrown backward in hyperextension. The odontoid process was tilted so that it was avulsed on the left side and still partially intact on the right. It was also observed that the fracture-dislocation at C4–C5 was unilateral and right-sided, and that the facets at this location were apparently intact. This indicated a blow to the left frontal area with a contrecoup unilateral dislocation and hyperextension type of cervical spine injury so that damage was most marked to the right side of the spinal cord. This would account for the residual Brown-Séquard pattern with the severe pyramidal tract signs on the right side. It will be noted that the patient initially had no movement in all four extremities and that internal rotation rapidly developed in the left hip, followed by flexion and extension of the left hip, thigh, leg and foot, and movement of the toes. The right lower extremity had shown merely right internal rotation. We believe that this patient has shown a marked return of function indicating a lesser degree of hematomyelia than edema. Swelling started to subside promptly and the appearance of function in the lower extremities was soon followed by return of bladder function and finally upper extremity movement. Recovery of finger movements, particularly on the right side, has been the very last function to reappear.

Case 9. G.S., a 49-year-old man, had suffered from arthritis of the cervical spine for 10 years. He retired at 1 A.M. on Oct. 17, 1951, after drinking a large quantity of beer. A few hours later he awakened, rose from his bed, and fell down a full flight

of stairs. Upon regaining consciousness a few minutes later, he could move only his upper arms slightly, but shortly thereafter became completely paralyzed in all four extremities.

The patient was transferred to University Hospital where he was found to be well oriented and cooperative. His neck was rigidly locked in hyperextension, so that the head remained elevated several inches above the table even after all support was withdrawn from under it. Palpation posteriorly over the cervical spine elicited marked tenderness at the C4 spinous process. There was a loss of all sensory modalities to the C4 dermatome on the right and C5 on the left. All four extremities were



FIGS. 18–20. *Case 9.* (18) Lateral roentgenogram showing a severely comminuted hyperextension injury of cervical spine with fracture-dislocation of C4 vertebral body anteriorly on C5. (Retouched) (19) Autopsy specimen exhibiting the markedly constricted spinal cord at C4–C5 interspace. (20) Multiple transverse sections of spinal cord with the uppermost one at the top of the specimen and the lowermost fully 6 neural segments below site of constriction. Central cord destruction may be seen throughout the entire specimen.

completely paralyzed. The right triceps and radial-periosteal reflexes were intact, but otherwise there was complete areflexia with no pathological reflexes.

Roentgenograms of the cervical spine showed pronounced comminution and fracture-dislocation of C4 vertebral body anteriorly on the C5 vertebra (Fig. 18).

Crutchfield skeletal tong traction was applied after placing the patient on a Stryker frame. The intercostal muscles had been immediately paralyzed, and gradually the diaphragmatic respirations became more labored. The patient succumbed at 4 A.M. on Oct. 20, 1951.

Autopsy disclosed a severe crushing destruction of the cervical cord immediately at the site of fracture-dislocation, with central cord destruction several segments above and below the site of the injury (Figs. 19 and 20).

Comment. The roentgenograms demonstrate clearly that the injury occurred in hyperextension resulting in a complete crushing of the spinal cord at the C4–C5 interspace. The fracture-dislocation of the arthritic spine could have caused anterior cervical cord compression while hyperextension could

have effected posterior cord compression by the ligamentum flavum or the overlying laminae. There was complete pulping of the spinal cord with central extension of damage, both cephalad and caudad over a distance of seven or eight cord segments. With cephalad extension the residual functioning diaphragmatic neural segments were compressed and death occurred from respiratory failure.

DISCUSSION

Upon reviewing the 6 cases abstracted from the literature and the 9 cases presented by the authors, the majority of the group have had several important factors in common:

1. Most of these patients showed evidences of acute central cervical cord injury characterized by more motor impairment in the upper extremities than in the lower ones. Foerster[12] placed the sacral segments as the most lateral component of the lateral corticospinal tract, with the lumbar, thoracic, and cervical components arranged in that order proceeding medially toward the central canal (Fig. 21). As edema subsides recovery of function follows

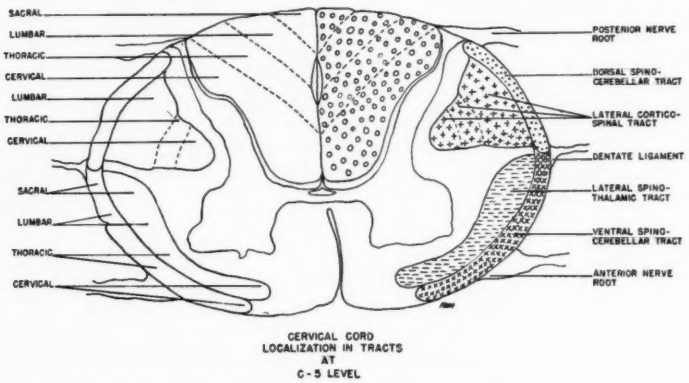


FIG. 21. Cervical spinal cord section at C5 level illustrating the localization within the various fiber tracts.

a definite pattern with motor return in the lower extremities first, bladder function next, and finally movement in the upper extremities with finger motion recovering last. From our experiences with Cases 2 and 8, the fibers to the internal rotators of the hip seem to be the most lateral in the pyramidal tract and those for the finger movements are the most medial. The fibers controlling motor and sensory conduction of impulses to the bladder apparently either lie somewhere between these extremes or are more refractory to damage than those of the lower extremities.

It is conceivable that the acute central cervical cord injury pattern might be responsible for the complete recovery reported in a few patients who have

had a brief but total tetraplegia. For this to occur some degree of motor function probably must return within a few hours after injury.

This type of injury may also account for the patient who has a "complete" tetraplegia with loss of all sensory modalities but still exhibits deep reflexes in the lower extremities or perhaps a flicker of voluntary motion in the feet, which has on occasion been called "reflex activity." The latter designation had been incorrectly made since the transected spinal cord at that stage would be presumably in the stage of "spinal shock." If the central damage, hematomyelia, increases, these neurological findings may disappear, and occasionally may lead an examiner to doubt whether these unusual signs had been elicited originally.

2. Segmentation within the sensory fiber tracts is also demonstrated in the diagram (Fig. 21). It will be observed that there is considerable obliquity of the distributions for various regions of the body rather than the usual arbitrary perpendicular divisions of the posterior columns seen in so many anatomical sketches. From our findings in Case 1, and several other cases of cord injury seen in the past, we are inclined to feel that at least a part of the vibration sensation is carried in the ventrolateral white matter of the spinal cord instead of the posterior columns alone. This tends to confirm the work of Petrén.[23]

3. Facial abrasions, contusions and lacerations or the history of striking the forehead suggest a hyperextension type of injury.

4. Acute central cervical cord injury is apt to occur most frequently in hyperextension injuries, particularly in the older age group when there is concomitant cervical arthritis and often no evidence of bony damage. However, the syndrome also does occur more rarely in certain hyperextension injuries with fracture-dislocation or compression fracture of the cervical spine, and on one occasion we have seen it in an unusual flexion fracture-dislocation (Case 7).

5. In 2 cases in this series head injury has been observed with contrecoup hyperextension injury to the cervical spine and spinal cord (Cases 3 and 8).

6. In those cases in which postmortem examination was made cord damage was tubular, central and extended over several cervical segments.

MECHANISM OF INJURY

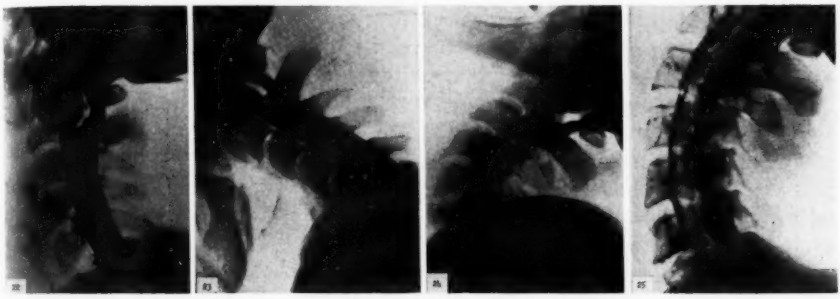
It is believed that Bennett in 1859[4] was the first person to make the anatomical observation that central hematomyelia of the cord could occur without any significant injury to the bony spine. He described the case of a drunken woman, who was kicked in the back of the neck by her husband. The blow resulted in immediate paralysis of all four extremities. The patient died 4 days later and at autopsy a clot of blood about the size of a pea was found in the center of the cord immediately below the medulla oblongata. The external portion of the cord and the vertebral bones were unaffected. Other extensive reports on either traumatic or spontaneous hematomyelia have been made by Benda,[3] Bufe,[8] Cohn,[9] and Schlesinger.[24]

Marty[20] reported a group of 78 cases of "traumatic hematomyelia," which he had collected from the literature. These were broken down into the following categories: fracture of the spine 7, dislocations 2, injury wounds without fracture or dislocation 25, violent muscular effort 8, traction on the limbs 3, dystocia 7, abrupt variation in blood pressure 14, and secondary effusions 12. Upon reviewing his paper carefully, one realizes that a fairly high percentage of these patients must have had some type of a vascular abnormality or other cord lesion that ruptured upon effort. It is very difficult to say how many of them sustained hematomyelia from an actual traumatic lesion to the spine without any fracture or dislocation.

However Marty's paper does call attention to the fact that some of his cases of hematomyelia might have resulted from some type of stress or compression of the spinal cord by a soft-tissue structure. Since no abnormality is visualized in the roentgenogram of the spine in many instances, the two most likely soft-tissue etiological agents are the sudden protrusion of an intervertebral disc or a wrinkling of the ligamentum flavum in cases of hyperextension of the cervical spine.

Middleton and Teacher,[21] Goldthwait,[15] Brooke,[7] Schneider,[25] and Symonds,[29] have reported cases of acute paraplegia secondary to acute herniation of an intervertebral disc. Cramer and McGowan[10] have emphasized the importance of so-called "recoil" injuries of the spinal cord and the role played by the intervertebral disc. The authors believe that ruptured intervertebral disc injuries are more apt to occur in acute flexion injuries of the cervical spine in which there is a sudden squeezing of the disc posteriorly into the spinal canal, resulting in contusion of the cord with an anterior cervical cord injury pattern.

For an understanding of one of the main mechanisms responsible for the acute central cervical cord injury syndrome, the highly important contribution made by Taylor[30] *should be emphasized.* He has shown that there may be extensive impingement of structures into the cervical canal without damage to the vertebral column. Taylor believes that "the injury is caused by hyperextension of the cervical spine without temporary dislocation, and the agent which impinges upon the cord is the forward bulging ligamentum flavum." He performed pantopaque cervical myelography on cadavers with normal cervical spines, taking roentgenograms in marked flexion, neutral, and forced hyperextension positions of the cervical spine (Figs. 22, 23, 24). In the last position a series of indentations appeared on the posterior surface of the spinal column opposite the interlaminar spaces. The defects appeared to be caused by the inward bulge of the compressed ligamentum flavum so that the outline of the canal was narrowed by at least 30 per cent posteriorly. If the same technique was employed when there was osteophyte formation on the posterior margin of the cervical vertebral bodies in senile spines, Taylor showed that these fixed protrusions further markedly impinged upon the anterior portion of the spinal canal (Fig 25). In the cervical cord injury patient, this would result in a pinching or squeezing type of compression.



FIGS. 22–25. Cervical myelograms performed on *normal cadavers* by A. R. Taylor. (22) Neutral position. (23) Flexed position showing no defect in pantopaque column. (24) Forced hyperextension demonstrating posterior indentations on the column at C3–C4, C4–C5, and C5–C6 interlaminar spaces, probably by ligamentum flavum. (25) Cervical myelogram in hyperextension made on *cadaver with hypertrophic spurring* at C4–C5, C5–C6 and C6–C7, illustrating potential impingement on column anteriorly plus posterior compression of the medium posteriorly by the ligamentum flavum. (Reprinted by courtesy of Dr. A. R. Taylor.[30])

Kahn[17] has called attention to the rôle of the dentate ligaments in restraining the spinal cord over calcified lesions of the cervical area, resulting in chronic anterior spinal cord compression. Since publication of this article there have been numerous reports dealing with the problem of the neurological manifestations of cervical spondylosis.[2,6,26,27] These arthritic spurs may also play a vital part in acute spinal cord injuries.

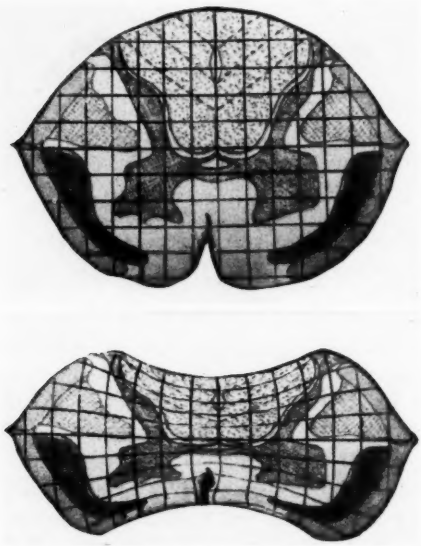
It is apparent that the cervical spinal cord may be simultaneously compressed by an arthritic spur or a disc, either protruded or calcified, and the ligamentum flavum both from the anterior and posterior direction, respectively, without distortion of the bony spine.

In an attempt to reconstruct the stress problem in hyperextension cervical spinal cord injuries, one of us (HP) constructed a model of a transverse section of the cervical spinal cord, using foam rubber for the cord. This was surrounded by a firmer layer of rubber to represent the pia mater and dentate ligaments. A pattern representing the gray matter and fiber tracts was sketched on the model prior to compression in semicircular vise-like jaws (Fig. 26).

The model was then studied in degrees of compression and repose. First a transparent grid was placed on the model before compression and then the distorted grid was drawn directly on this superimposed grid. The degree of displacement of the points assumed to be proportional to the magnitude of the stresses was measured and plotted to form the curves obtained below.

In studying the compressed section (Fig. 27) it became apparent that several stresses were set up.

1. Anteroposterior compressive stresses (Fig. 28).
2. Longitudinal tensile stresses caused by postero-anterior displacement of nerve fibers with extension of damage in both cephalad and caudad sections (Fig. 29).



FIGS. 26–27. (*Above*) Model of cross section of cord with pathways shaded. (*Below*) Model compressed both by an anterior and posterior force, demonstrating the distortion of spinal cord fiber tracts.

3. Longitudinal tensile stresses set up by lateral displacement of the nerve fibers (Fig. 30).
4. Torsional stresses in posterolateral and anterolateral areas (Fig. 31).

The model shows that the predominant stress is the anteroposterior compressive stress. Its magnitude diminishes laterally as indicated by the length of the arrows (Fig. 28).

The longitudinal tension set up by the postero-anterior displacement of fibers when the cord is compressed is a secondary effect (Fig. 29). This stress diminishes proportionately as one recedes from the maximum stress area (shaded). Since the cord substance of the dorsal and ventral white columns forms a loose mesh more damage can be expected in these areas from the tensile forces than from the compressive forces. The brittle or inelastic elements can slip by each other to escape immediate compression, but the tensile forces act as soon as the fibers are displaced and thus failure in tension is more likely.

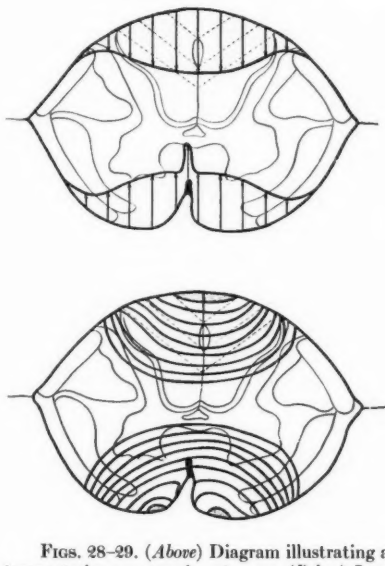
Since there is very little displacement around the central canal the gray commissure fibers are not subjected appreciably to tensile stresses and avoid the great compressive stresses by slipping in this loose medium. Also because the ventral notch in the cord displaces the maximal compressive stresses slightly to the left and to the right of the midline, the fibers are spared further.

In examining the lateral regions of the spinal cord it will be noted that

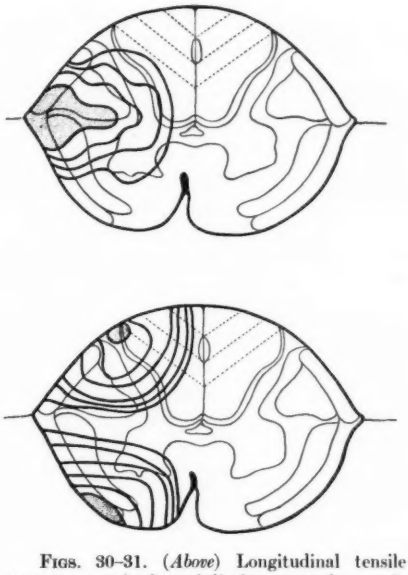
the compressive stresses decrease rapidly as the outer portion of the cord is approached (Fig. 28). In the hand and arm region of the pyramidal tract, for example, the compressive stresses are about five times greater than those in the leg portion. This can be seen when the lengths of the arrows are added. The ratio of the tensile stresses caused by postero-anterior displacement of fibers in these regions is much less than the compressive stress ratio.

The tension set up by the lateral displacement of the fibers (Fig. 30) is small compared to the two stresses mentioned above. Little damage can be expected from this force unless the fibers are very brittle or inelastic. This is also true for the torsional stresses (Fig. 31) resulting from the angular displacement of the nerve fibers when the cord is compressed. It should be mentioned that the more the compressing jaws approach a wedge shape the greater become the torsional stresses.

In summary: in the lateral white columns, because of the crowding of fibers, compressive stresses are more damaging than the other stresses in the sagittal direction, since they involve the most anterior regions of the lateral spinothalamic tracts and the most medial regions of the lateral corticospinal tracts. The tensile stresses, although minor, are more likely than compressive stresses to cause damage in the ventral and dorsal white columns. The torsional and tensile stresses can be held responsible for the caudad and cephalad extension of damage.



FIGS. 28–29. (*Above*) Diagram illustrating anteroposterior compressive stresses. (*Below*) Longitudinal tensile stresses caused by postero-anterior displacement of nerve fibers with extension of damage in both cephalad and caudad segments.



FIGS. 30–31. (*Above*) Longitudinal tensile stresses set up by lateral displacement of nerve fibers. (*Below*) Torsional stresses in posterolateral and anterolateral areas.

The model described above obviously does not take into consideration numerous important structural features found in the spinal cord. No note has been made of the fact that the major portion of the vascular supply of the anterior two-thirds of the cord is primarily derived from the anterior spinal artery, and that the very presence of these structures may lend an increased consistency to this area. The central canal permits adjustments of pressure with different degrees of compressibility and, as a result, the pain and temperature fibers which cross beneath this zone may not necessarily be destroyed in spite of the marked stress applied to them. The part played by variations in size and type of fibers, particularly with regard to sensory conduction, is important. It should also be noted that the sensory fiber tracts in general lie well out toward the periphery of the cord so that the pathways themselves may merely suffer from edema, rather than undergo complete destruction. As a result, many of these patients do not show the complete sensory deficit that one might anticipate.

PATHOLOGY

For years observers[5,18,33,34] have stated that hematomyelia is more prone to occur in the central gray matter of the spinal cord where the tissues have a relatively looser texture and less supporting strength than in the surrounding white matter. The hemorrhage may progress centrally through several

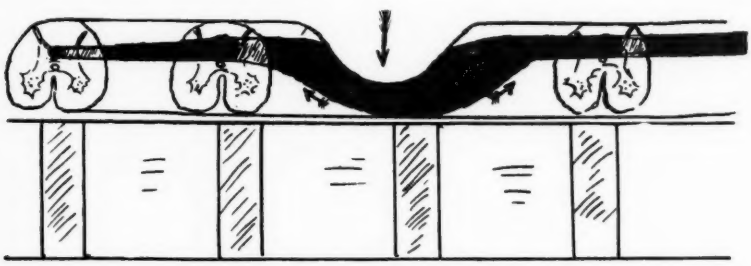


FIG. 32. Diagram demonstrating the extent of central spinal cord damage in experimental crushing injuries to the cord. The arrow indicates the point of cord compression but generalized central pulping of the cord extends both cephalad and caudad for several segments. (Reprinted by courtesy of Dr. J. F. McVeigh.[19])

segments causing compression of the white matter. This has been beautifully illustrated in the work of McVeigh[19] on experimental cord crushes with the extension of a longitudinal force resulting in pulping along the central canal of the cord over several segments both cephalad and caudad to the injury (Fig. 32). If damage is sufficiently severe there may be associated destruction of the white matter. The surrounding tissues exhibit edema with fragmentation of the myelin and the nerve cells may be injured to varying degrees. This diffuse damage had been attributed previously to anterior spinal artery thrombosis. Allen[1] has demonstrated experimentally that the degree of re-

covery is proportional to the amount of edema present compared to the amount of destruction.

In 1915, Holmes,[16] *discussing concussion of the spinal cord, observed that even though there was no fracture or dislocation of the spine in some spinal cord injuries, there was either no gross evidence of damage to the cord or a uniform swelling opposite the point of impact.* He agreed with Fickler that, since the spinal cord was bathed in cerebrospinal fluid, it could oscillate back and forth with trauma to the vertebral column. Since oscillation of the cord will be asynchronous with that of the bony spine, the spinal cord will impinge upon the spine with resultant bruising. Simultaneously the sudden jarring of the spinal cord will produce physical disturbance in the tissue "especially in the fluid axioplasm of its fibers." This explanation leaves much to be desired. From the following description by Holmes of the microscopic sections in cases of concussion, the authors feel that the pathological findings may well apply to hyperextension of the spine with a sudden squeeze of the cord as a result of simultaneous anterior and posterior cord compression.

In Holmes' spinal cord cases of concussion, the most remarkable change noted microscopically was the edema throughout the affected segments. This was pronounced at the site of impact. In some cases there was complete destruction of certain tracts. Usually only a part of the fibers in the affected tracts had been completely destroyed, but in the remainder of the fibers the myelin sheaths and the axis cylinders were swollen. In the gray matter there were focal areas of softening usually unassociated with the hemorrhages which themselves had peripheral zones of neuronal degeneration.

These pathological findings of severe edema would account for the initial presence of neurological signs and symptoms which later subsided in the hyperextension injuries that we have presented. Thus far we have not had sufficient pathological material of our own to confirm these beliefs.

No attempt has been made to present the chronic sequelae of central cord damage or its therapy. These have been reserved for a later paper.

TREATMENT

The recognition of the syndrome of acute central cervical cord injury is important, for if these symptoms are found surgical intervention is contraindicated. The following reasons are listed:

1. Spontaneous recovery may occur. In 1918 Frazier[13] observed that "hematomyelia uncomplicated and dissociated from any other effect of the injury is not an operable lesion." He did not indicate how such a diagnosis could be made with certainty. The acute central cervical cord injury syndrome suggests the presence of hematomyelia or/and edema. In our Cases 3, 5, 6, 7 and 8 partial to complete recovery occurred without exploration or without surgery on the spinal cord itself.

2. Decompressive laminectomy is futile because in most instances in which the acute central cervical cord syndrome is present there is no subarachnoid block to overcome. The presence of a complete block on the

Queckenstedt test is one of the criteria for operation listed by most neurosurgeons. In 7 of our 9 patients lumbar puncture was performed at varying intervals after the patient's injury. In spite of the severity of damage to the cord, there was no complete blockage in the subarachnoid space on the jugular vein compression test. Instead of swelling occurring only at the point of impact in these cases, it is distributed centrally or tubularly throughout several segments of the cord. As a result there is no block.

One must decide whether cervical myelography should be performed. The manipulation necessary to obtain a successful cervical myelogram requires acute hyperextension of the cervical spine so that the radio-opaque medium will not pass upward through the foramen magnum. Since in a fairly large number of patients the spinal cord injury developed in hyperextension, cervical myelography might further damage an already compromised spinal cord. This is, of course, also true for those patients who have this pattern, but have sustained their injuries either in hyperextension or in flexion with associated fracture-dislocation of the cervical spine. In addition to the dangers of performing myelography there is the fact that the procedure is only of questionable value in patients with this syndrome. Pathologically the cord may show no gross lesion on the surface, or there may be slight local swelling both proximal and distal to site of the lesion. The myelogram, therefore, may show no lesion, single extensive midline involvement, or several midline defects.

3. Pial incision over the dorsum of the involved cord has been advocated in hematomyelia to relieve spinal cord swelling. If this procedure had been attempted in the cord visualized in Case 1 (Fig. 3) it would have been virtually impossible not to start accidental hemorrhage and further injury to the spinal cord.

4. Myelotomy in these cases of acute central cervical cord injury may cause not only disruption of normal vessels but also may damage an edematous but otherwise normal cord. Frazier emphasized that the hemorrhagic areas in hematomyelia were multiple and of small dimensions and were distributed through several segments so that removal was not feasible. The authors agree with this policy. The problems related to myelotomy are readily apparent upon observing the figures in Cases 1, 4, and 9.

From an historical standpoint it should be noted that this conservative approach is in direct contradiction to the reports of other clinical and experimental observers. In man, Elsberg[11] believed that in the rare case in which hematomyelia was diagnosed an incision of the dorsal column should be made. In lecturing on spinal injuries in warfare, Holmes[16] commented that in contusion injuries, for a myelotomy to be successful a longitudinal incision of the cord must be done within a few hours after infliction of the injury. "This is rarely possible in warfare, the early symptoms are so equivocal that if resorted to more harm than good might easily be done."

Three interesting articles have been written about the experimental production of acute crush injury to the spinal cord and its treatment. As a result

of his classical experimental work Allen[1] believed that symptoms produced by severe contusion of the spinal cord could be relieved by laminectomy and incision of the dorsal columns with drainage of edematous and hemorrhagic intramedullary tissue. This permits expansion or decompression of the residual intact spinal cord fibers. Freeman and Wright[14] presented experimental work similar to Allen's and, in carefully controlled studies, discovered that there was symptomatic improvement in animals with cord contusions when laminectomy with pial incision and dorsal myelotomy was performed. In an excellent paper which has not received sufficient attention in the literature on the subject, McVeigh[19] estimated that edema comes on within 8 hours and increases with the length of time that the animal survives. He indicated that time is a factor and marked intrapial pressure is developed as a result of this edema. "This becomes apparent when the dura and pia are incised and this pressure is released. Judging from the cases in which the dura was nicked, it seems that the operative procedure would cause a further destruction of cord without relief of edema in the areas of the cord often affected. The release of pressure seems to have no effect in checking edema formation."

5. Exploration further disabled one of our two surgically treated patients (Cases 1 and 2) in whom there was no visible bony damage. It was believed that this was caused by manipulation of the cord at operation in our attempt to cut the dentate ligaments and explore anterior to the cord. The slightly impaired lower extremity components of the lateral corticospinal tract lie near the surface of the cord and even slight pressure was probably sufficient to cause complete impairment of function.

In the conservative treatment of those patients who have no bony distortion of the spine it is probably most satisfactory to merely place the patient in a neutral position with traction applied in the plane of the body until cord swelling or edema has subsided. *Hyperextension must be carefully avoided for fear of causing more damage to the cord with cephalad extension of edema, possibly resulting in respiratory embarrassment and death.* Traction may be replaced by a firm fitting collar after 4 or 5 weeks. If the syndrome is associated with a fracture-dislocation, a cervical fusion may eventually be necessary. It is wise to wait, if possible, for a period of 3 or 4 weeks until there has been as complete a regression of cord edema as possible prior to exposing the cervical spine and inserting a bone graft.

Since motor recovery, if it occurs, is last to return in the fingers in acute central cervical cord injury above the C6–C7 interspace, it should be emphasized that early adequate physiotherapy should be administered and continued for many weeks to prevent contractures and periarthritis of the hands and arms.

The prognosis in acute central cord injury is probably considerably superior to the outcome in those patients who have sustained an acute flexion injury with anterior spinal cord compression. In the central cord type of injury, there may be merely massive edema about some of the fibers with in-

complete destruction. These fibers are compressed rather than completely severed as so often occurs in acute cervical flexion injuries.

SUMMARY

There is a syndrome of acute central cervical spinal cord injury characterized by disproportionately more weakness in the upper than in the lower extremities with some impairment of the bladder. Associated pain and temperature loss is found in early phases and in the more severe cases there may also be impairment of touch, motion, position and vibration sensations.

The prognosis for patients with such symptoms and lesions may be relatively good with motor power returning in the lower extremities first, bladder function recovering next, and finally movement in the upper extremities. The motion of the fingers is the very last to return. Sensory recovery does not pursue an orderly pattern.

The degree of recovery is directly proportional to the amount of edema as compared to hematomyelia, ranging from complete recovery to total destruction with ascending hematomyelia and death.

The mechanism of production of such lesions is described with particular reference to hyperextension injuries of the spine. In a number of the cases cited, no bony injury to the spine but only bony spurring could be demonstrated either by roentgenogram or at operation; in others, certain types of fracture-dislocation or compression fracture of the cervical spine were present.

The symptoms in acute central cervical spinal cord injury are caused by a compression of the spinal cord simultaneously from both anterior and posterior surfaces when hyperextension occurs, so that nerve fibers are not so apt to be totally disrupted as they are in acute flexion injuries of the cervical spine.

Re-emphasis should be placed on the importance of noting the presence of facial injuries as an indication of possible acute hyperextension of the cervical spine. In some of these patients the acute central cervical cord injury syndrome will be found, and, if it is, surgical intervention is contraindicated.

Nine cases of our own are reported in detail and 6 other cases selected from the literature which support the above theses are also presented.

Two of the patients had injury to one side of the head resulting in hyperextension of the neck and contrecoup cervical spinal cord injury.

The authors wish to express their deep appreciation to Dr. Merle Musselman, Director of Surgery, Wayne County General Hospital and to Dr. Robert Bailey, Orthopedic Consultant to that institution, for the opportunity of reporting Case 3. Drs. John Webster and James Lofstrom of City of Detroit Receiving Hospital also have very kindly permitted the use of the same patient's case history and roentgenograms.

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CONCERNING THE NEURAL MECHANISM OF PARKINSONIAN TREMOR

E. JEFFERSON BROWDER, M.D., AND HARRY A. KAPLAN, M.D.

Department of Neurosurgery, State University of New York, College of Medicine at New York City, and Neurosurgical Service, Kings County Hospital, Brooklyn, New York

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A RECENT favorable report[3] advocating surgical occlusion of the anterior chorioidal artery for symptomatic relief of patients with parkinsonism led us to try this operation. Alteration in the frequency of tremor of the extremities contralateral to the side in which the artery was occluded was unique and prompted the present report. This unusual postoperative feature consisted of a reduction in rate of tremor to approximately one-half of that prevailing on the side unaffected by the procedure. The finding was present in 2 of the 5 patients thus far submitted to surgical occlusion of an anterior chorioidal artery.

REPORT OF CASES

Case 1. *Bilateral parkinsonism of 30 years' duration. Severe rigidity with minimal tremor. Surgical occlusion of right anterior chorioidal artery. Moderate reduction of rigidity and change in rate of tremor of extremities of the left side.*

Kings County Hospital, 53-45611. F.N., a 43-year-old male, was admitted on Oct. 1, 1953 with obvious signs of advanced parkinsonism. Following a bout of encephalitis in 1923, symptoms and signs of Parkinson's disease developed. These gradually increased in severity until 1937, when walking became difficult. Rigidity progressed slowly to produce almost complete incapacitation and for this reason he was brought to the hospital.

Examination. He was a well developed, poorly nourished male. Pupils were round, regular, equal and reacted to light and in accommodation. There was an external squint of the right eye caused by weakness of the right internal rectus muscle. Masked facies with infrequent blinking was present. Marked rigidity to passive movement was noted in the extremities of the left side and moderate rigidity on the right side. At irregular periods a rhythmic tremor with a rate of 4 to 6 per sec. was present in all extremities, more evident on increased emotional stress.

Course. The patient was observed on the wards of the neurological service for 4 months. He was confined to a wheel chair throughout the day. Occasional attacks of oculogyric crises were observed during this period. There were no gross changes in the general physical status.

Operation. On Feb. 25, 1954, through a right frontotemporal craniotomy, the temporal lobe of the brain was retracted and the right internal carotid artery was exposed. The anterior chorioidal artery arose as a single trunk from the distal part of the carotid and shortly trifurcated. The artery was occluded at the carotid by electrocautery and clips. Hemostasis was effected and the wound was closed with layer silk.

Postoperative Course. On the 1st day after operation lethargy prevailed but cooperation could be gained on repeated commands. Tremor and rigidity were less in the left than in the right extremities. There was diminished response to pin prick on the left side as compared to the right and weakness of both the left upper and lower extremities could be demonstrated.

By the 5th postoperative day, the patient was alert enough to fully cooperate in examination. Tremor and rigidity were obviously less on the left than on the right side. A left homonymous hemianopsia was present, demonstrable by confrontation. At this time the weakness and hypalgesia of the extremities of the left side were not as evident.

On the 6th day, at irregular intervals, a difference in frequency of tremor of the lower extremities was observed. During these periods the rate of tremor of the right foot was $4\frac{1}{2}$ per sec., while that of the left was $2\frac{1}{4}$ per sec. and of greater amplitude (Fig. 1). The rate of tremor of the upper extremities was equal. At times during the next month tremor of the extremities of the left side was absent, on occasions present and equal in rate to that of the right side, and on other occasions occurring in bursts at a rate of one-half that of the right side.

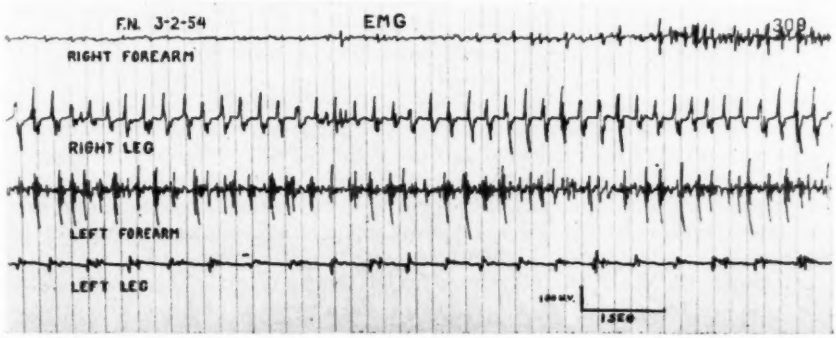

FIG. 1. Electromyogram demonstrating frequency of muscle potentials of the extremities. The right leg has a frequency of $4\frac{1}{2}$ per sec. and the left leg of $2\frac{1}{4}$ per sec.

On the 7th day it was noted that excessive quantities of water were being consumed. Urinalysis disclosed a specific gravity of 1006. The specific gravity of the urine recorded pre-operatively was 1024. The polydipsia and polyuria persisted for 2 months. Oculogyric crises with the head and eyes turned to the right continued and there were bouts of uncontrollable loud crying necessitating isolation.

After the 3rd postoperative week the hemianopsia was not present. The periodical reduction in rate of tremor of the extremities of the left side, as described, persisted for 1 month after operation.

Comment. This subject manifested the end stage of paralysis agitans, namely a hesitant, whispering, monotonous speech, masked facies, marked rigidity with a striking paucity of purposeful movements, and rhythmical tremor more noticeable during perturbation of the conscious state. After operation on the 6th postoperative day, the rate of tremor of the extremities of the left side was found at irregular intervals to be one-half of the rate that

had existed in these parts prior to operation and one-half of that of the extremity of the right side. The amplitude of the tremor on the side affected by operation was greater in the foot than in the hand, was abolished by purposeful movement and ceased temporarily after restraining the part. In other words, this modified tremor was identical with that commonly observed in any patient with parkinsonism with the exception of its rate. Rigidity was moderately reduced following operation and this has endured up to the present time (4 months). The incapacity of the patient to care for himself was the same following operation.

Case 2. *Bilateral parkinsonism of 9 years' duration. Moderate rigidity and striking tremor. Surgical occlusion of the left anterior chorioidal artery. Postoperative reduction of rigidity and change in rate of tremor of extremities of the right side.*

Kings County Hospital, 54-10645. R.S., a 53-year-old male, was admitted on March 9, 1954 with obvious signs of parkinsonism. Nine years prior to entry tremor developed in the right upper extremity and 2 years later in the left upper extremity. Difficulty in gait had been present for 4 years before admission. Seemingly the disease had gradually increased in severity since onset. Because of periodic bouts of weakness and falling he was brought to the hospital.

Examination revealed a well developed, fully cooperative, fairly well nourished male. There was masking of the facies with infrequent blinking. He walked with short, rigid steps without swing of the arms. Tremor of moderate amplitude and at a rate of approximately 5 per sec. was present in all extremities. Rigidity was greater in the extremities of the right than in those of the left side. Purposeful movements were initiated less readily with the extremities on the right side. Tendon reflexes were equal bilaterally. Abdominal reflexes were weakly obtained on the left but were not present on the right side. Babinski toe sign was present on the right side. Although moderately incapacitated he was able to care for himself on the ward.

Operation. On March 18, 1954, through a left temporal craniotomy, the temporal lobe was retracted and the left anterior chorioidal artery was occluded with cauterization and three silver clips.

Postoperative Course. On the 1st day after operation the patient was lethargic but when aroused was cooperative. A right homonymous hemianopsia could be demonstrated by confrontation. A right hemihypalgesia was present. There was mild paresis of the right upper extremity. Tendon reflexes were slightly more brisk on the right. Abdominal reflexes were not obtained bilaterally. The right Babinski toe sign was more easily demonstrated on the right than it was before operation. Rigidity was less in the extremities of the right than in those of the left side. Tremor in the extremities of the left, or side unaffected by operation, remained unchanged. At this time no tremor was demonstrable in the extremities of the right side.

On the 2nd day, the hemianopsia remained the same; however the hypalgesia and paresis of the right side were less evident. Tremor of the right upper extremity was absent but the tremor in the right leg had returned. Slight rigidity was present in the right upper but more so in the right lower extremity.

The patient's general condition gradually improved and he was out of bed on the 5th postoperative day. On April 4, the 17th postoperative day, tremor was sporadically present in the right upper extremity, appearing at a rate one-half that of the left side. Upon placing the forearms over the edge of an arm rest, with the hands hanging loosely, the modified tremor of the right hand could be accentuated.

Electromyograms demonstrated the tremor of the left upper extremity to be 5 per sec. and that of the right upper extremity to be $2\frac{1}{2}$ per sec. in frequency (Fig. 2). This reduction in rate of tremor on the right side persisted at irregular intervals for 3 months.

Comment. This subject was ambulatory, moderately intelligent and fully cooperative. Alteration in the tremor of the extremities of the right side, observed for the first time on the 17th day following operation, was at a rate one-half of that which existed pre-operatively, and was abolished by pur-

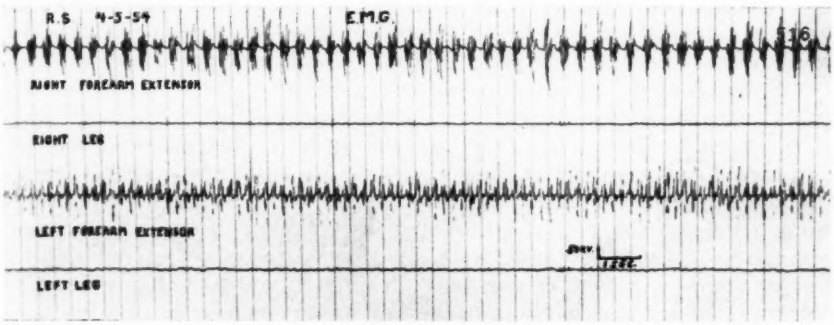

FIG. 2. Electromyogram demonstrating frequency of muscle potentials of the extremities. The left forearm has a frequency of 5 per sec. and the right forearm of $2\frac{1}{2}$ per sec.

poseful movements. This postoperative modification in tremor was identical with that observed on the left side in Case 1. Rigidity in the extremities affected by the operation was favorably modified and this improvement has persisted up to the present time (3 months). In fact the clinical result of this patient is the most satisfactory of the 5 submitted to surgical occlusion of an anterior chorioidal artery.

DISCUSSION

The passive tremor of parkinsonism occurs at a rate of 4 to 6 per sec. as recorded in the electromyogram. Rarely the rate may attain 8 per sec. In a series of 41 patients, each of whom had a minimum of four electromyograms in a period of 3 months, the relatively constant rate of 4 to 6 per sec. has been demonstrated. So far as we are aware no explanation has been offered for the occurrence of the tremor of parkinsonism at a rate of 4 to 6 per sec. Not only is this small feature of the disease obscure but the pathophysiological mechanism responsible for the entire syndrome is unknown. Even so there is evidence to support the belief that an abnormal neural circuit responsible for tremor and rigidity of parkinsonism exists within the nervous system. In our clinic, areas that have been surgically altered for modification of tremor and rigidity are the cortical motor mechanism and its immediate subcortical projections, anterior limb of the internal capsule[1,2] and the contiguous putamen, ansa and fasciculus lenticularis in the field of Forel H_2[4,5] zone irri-

gated by the anterior chorioidal artery, the cerebral peduncle at the level of the midbrain and the pyramidal pathway in both the cervical and lower thoracic spinal cord. It would therefore appear that all of these enumerated areas are concerned with an abnormal hypothetical circuit or pathway. The hypoxia subsequent to occlusion of an anterior chorioidal artery obviously implicates this pathway or pathways. Probably a sublethal injury to the cellular elements acting as a generator of the proposed circuit results in a slowing of the frequency of their firing. Although no one has demonstrated electrical activity in the brain that could be interpreted as the stimulus for muscle contraction regarded as a tremor, impulses, either inhibitory or facilitatory, must be responsible for the peripheral manifestation of parkinsonism.

With only slight variation, the anterior chorioidal artery irrigates a small part of the uncus, the amygdaloid nucleus, passes through the posterior two-thirds of the posterior limb of the internal capsule to reach the subthalamus and mesial posterior part of the globus pallidus, entopeduncular nucleus of Papez, and then terminates in the chorioid plexus. All features considered, it would seem quite likely that the group of cells acting as a generator mechanism resides in the subthalamic zone. In all events a correct explanation for this reduction in rate of tremor to approximately one-half that which previously existed will probably open the way for a more complete understanding of the neural mechanism of parkinsonism.

CONCLUSIONS

Two out of 5 patients with parkinsonism submitted to surgical occlusion of an anterior chorioidal artery (Case 1, right side–Case 2, left side) were observed during the postoperative period to have in the extremities of the side contralateral to the occluded artery a modification of the pre-existing tremor. By electromyographic studies it was demonstrated that the rate of tremor in the parts affected by operation was in the ratio of 1 to 2 as compared to that of the opposite or unaffected side. In one patient this phenomenon persisted intermittently for 1 month and in the other for 3 months. The areas potentially implicated on the basis of our anatomical studies of the anterior chorioidal artery are recorded. Evidence derived from our results of the several operations for the modification of tremor and rigidity of parkinsonism and from the observations herein recorded supports the idea that probably within the subthalamic area resides the "controlling" mechanism of parkinsonism.

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GLUCOSE TOLERANCE IN PATIENTS WITH LOCALIZED LESIONS OF THE CENTRAL NERVOUS SYSTEM*

J. P. SEGUNDO, M.D., E. BALEA, PH.D., AND R. ARANA, M.D.
Laboratorio de Neurofisiología Clínica (Institutos de Neurología y de Ciencias Fisiológicas), Facultad de Medicina, Montevideo, Uruguay

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CONTROL of carbohydrate metabolism is fundamentally a function of the endocrine system. Neurohumoral mechanisms, though dispensable, are responsible for finer adjustments and for the integration of changes of glycemia in different patterns of response (sham rage, adaptation to cold, etc.[14,15,18]). Problems relating to this nervous regulation have been approached on different occasions by studying abnormalities exhibited by patients with neurological diseases.[1,9,12,23,28,29,31,33–37,39] The present paper describes an attempt to find further proof of the participation of the central nervous system in the control of carbohydrate metabolism and, at the same time, obtain knowledge of the structures involved. As tumors appear at any age, in patients generally without other diseases and in practically any region of the central nervous system, as they present a relatively well-known pathological physiology[5] and as they permit verification, they offer the opportunity of an analysis somewhat similar to that of a planned physiological experiment. We considered them, and a small number of other equally well-localized and verifiable lesions, as material better adapted to an investigation of the problem than that presented by other pathological entities and, therefore, proceeded to study them accordingly.

The correlation between localization of cerebral abnormality and associated disturbance of carbohydrate metabolism will necessarily have to be interpreted in a general way as neither radiologic nor operative observations are capable of elucidating, in a strict and detailed fashion, the entire extent and specific nature of neural structures that are involved. There exists the possibility, moreover, that these lesions may disturb function in the central nervous system through some mechanism that, as yet, remains obscure. These drawbacks, inherent in the handling of such clinical material, do not, in our opinion, proscribe its use for research analysis; nevertheless, they suggest that caution must be exercised in the interpretation of the available data.

MATERIAL AND METHODS

All patients in this series were under the age of 66 to avoid the influence of senility on the glucose tolerance curve.[35] Also, patients who had a family

* A brief abstract of this paper was published in *Arch. Soc. Biol. Montevideo*, 1953, *20:* 72–73.

history of diabetes were excluded as were those who had evidence of hepatic, endocrine or any other disease that could alter the glucose tolerance curve. The general condition of all individuals studied was adequate, none being terminally or severely debilitated.

As the study was undertaken to assess the influence of regional disturbances of the brain upon carbohydrate metabolism, the patients were divided into 2 groups. The first (Group I) contained only patients who had a disturbance of a lobe or part of the brain caused by the presence of a tumor mass that was later verified. The other (Group II) contained patients in whom a lobe or part of the brain was isolated or resected operatively. Primarily, the patients of Group I, therefore, were studied pre-operatively while those of Group II were evaluated postoperatively. In certain instances, however, postoperative determinations were made in patients of Group I (5 cases marked with asterisks in Table 1) and pre-operative examinations in cases of Group II for purposes of comparison.

Group I was made up of 43 patients, each with a localized lesion in the central nervous system that was both confirmed and localized by radiographic procedures (5 cases), by operation (34 cases) or by autopsy (4 cases). Most of these patients had tumors (34 cases) but 3 had hydatid cysts, 1 a giant and partially thrombosed aneurysm of the temporal fossa, 1 a spontaneous intracerebral hematoma, 2 platybasia with modifications of the cervical vertebrae, and 2 cervical spinal cord traumatic injuries.

Group II consisted of 7 leucotomized schizophrenics, 2 cingulectomized idiots, and a patient who, because of a large oligodendroglioma, was subjected to a right temporal lobectomy; this patient was included in Group II because she was not tested until after operation.

In making a classification of lesions or operative isolation according to localization, we accepted the gross anatomical divisions of the brain in main lobes and added those special regions that gave characteristic clinical syndromes[5] (corpus callosum, third ventricle, pineal body, suprasellar region). Admitting a possible functional significance,[13] we subdivided the major lobes as follows: frontal into precentral and prefrontal (convexity, orbital surface, white matter), temporal into convexity, basal surface, white matter, and deep (in the region of the basal ganglia and region of the third ventricle), parietal and occipital into convexity and white matter. Other lesions involved the cerebellum, the cerebellopontine angle or the cervical spinal cord. When, as frequently occurred, the lesion occupied more than one of the schematic regions described, it was included in each of the corresponding groups.

The same test was applied to all patients included in Groups I and II. The technique used for the glucose tolerance curve was that suggested by Levinson and MacFate.[25] For 3 days prior to testing, the patient was placed on a special diet that included an abundant supply of protein and carbohydrate; no complementary medication was administered but the routine diagnostic measures were performed. In patients subjected to pneumoencephalo-

graphy, the glucose tolerance curve was made 3 days after this procedure. After a fasting blood sample was taken by digital puncture, 1 gm. of glucose per kg. of body weight in a 30 per cent solution was given by mouth. Subsequently, samples were taken every 30 minutes till 3 hours had elapsed; in 5 patients, samples were taken at fasting, and at 30, 60, 120, 180 and 240 minutes. Glycemia was measured by the Hagedorn-Jensen procedure. The acceptable limits for variation for glycemia (mg. per cent) in normal cases were: 80–120 (fasting), 130–180 (30 and 60 min.), 100–150 (90 min.), 70–120 (120–150 min.), 80–120 (180–240 min.). Urine samples were analyzed for the concentration of glucose prior to the test (spontaneous glycosuria) and the total amount of glucose excreted during each test period (glucose tolerance curve glycosuria).

Abnormal curves were classified according to their characteristic appearance into 6 types:

Type A: hyperglycemia above the normal maximum (180 mg. per cent) which reverted to normal levels within 3 hours (Fig. 1A).

Type B: hyperglycemia that did not exceed the normal limit of elevation but that did not return to normal levels within 3 hours (Fig. 1B).

Type C: exaggerated and persistent hyperglycemia (Fig. 1C).

Type D: glycemia variations that, when plotted (Fig. 1D), exhibited a curve of the usual shape but that was so flat it did not exceed the limits accepted as normal for fasting glycemia (80–120 mg. per cent).

Type E: normal elevation followed by a marked hypoglycemia (Fig. 1E).

Type F: curve with moderate variation (Fig. 1F) but with unusual shape (retarded

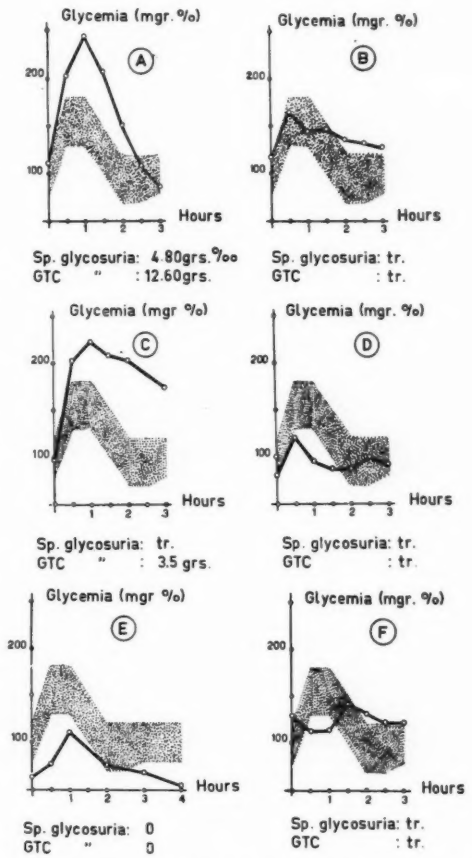

FIG. 1. Different types of abnormal glucose tolerance curves. (A) Type A; (B) Type B; (C) Type C; (D) Type D; (E) Type E; (F) Type F. Normal curves fall inside stippled area. Sp. = spontaneous. GTC = glucose tolerance curve. Tr. = traces.

TABLE 1

Glucose tolerance curves in cases of localized lesions of the central nervous system

Case No.	Localization	Glycosuria		Fasting Glycemia	Type of Glucose Tolerance Curve
		Spontaneous	Glucose Tolerance Curve		
	PREFRONTAL:				
	Convexity				
23		Tr.	—	115	B
58		—	—	110	A
105*		—	—	86	A
	White Matter				
18		—	—	99	C
37	Bilateral	4.8	9.6	111	A
43	W.M. & Cor. Cal.	—	4.4	119	C
84	W.M. & Cor. Cal.	—	—	81	N
107		Tr.	Tr.	95	N
	PRECENTRAL:				
9		—	—	104	D
59*	Prec.-Par.-Occ.	—	Tr.	97	A
92		—	Tr.	93	N
109		—	Tr.	97	N
	TEMPORAL:				
	Basal surface				
20	B.S. & S.	—	—	88	E
99*	B.S. & S.	Tr.	Tr.	80	D
108		—	Tr.	102	A
	White matter				
51	W.M. & Par.	—	Tr.	101	C
55		—	Tr.	102	A
98	W.M. & Par.	—	3.5	99	C
94		—	Tr.	79	A
	Deep				
65	D.T.-Occ.-3rd v.	Tr.	Tr.	129	F
93		—	Tr.	102	F
110		—	—	81	C
	PARIETAL:				
	White matter				
26	W.M. & Occ.	—	—	95	N
30*	W.M. & Occ.	—	—	131	C
59*	W.M.-Prec.-Occ.	—	Tr.	97	A
51	W.M. & Temp.	—	Tr.	101	C
98	W.M. & Temp.	—	3.5	99	C
	CORPUS CALLOSUM:				
43	Cor. Cal. & W.M. Pref.	—	4.3	119	C
84	Cor. Cal. & W.M. Pref.	—	—	81	N
	OCCIPITAL:				
	White matter				
26	W.M. & Par.	—	—	95	N
30*	W.M. & Par.	—	—	131	C
59*	W.M.-Prec.-Par.	—	Tr.	97	A
65	W.M.-D.T.-Par.	Tr.	Tr.	129	F
	THIRD VENTRICLE:				
1	In the ventricle	—	—	63	E
100	In the ventricle	—	—	77	D
65	3rd v.-D.T.-Par.	Tr.	Tr.	129	F

TABLE 1—*continued*

Case No.	Localization	Glycosuria		Fasting Glycemia	Type of Glucose Tolerance Curve
		Spontaneous	Glucose Tolerance Curve		
	PINEAL:				
95		—	—	104	F
	SUPRASELLAR:				
47		—	1.8	136	A
86*		—	Tr.	84	E
2	S. & B.S. Temp.	—	—	88	E
99*	S. & B.S. Temp.	Tr.	Tr.	80	D
	CEREBELLUM:				
25		Tr.	Tr.	99	A
32		Tr.	Tr.	109	A
40		Tr.	Tr.	132	A
52		Tr.	Tr.	124	C
62		—	—	102	B
	ACOUSTIC NERVE:				
36		Tr.	—	111	A
63		Tr.	—	101	C
80		—	Tr.	90	N
	SPINAL CORD:				
56	C-1	—	0.6	131	C
72	C-1	—	—	104	B
102	C-1	—	—	77	F
54	C-4	Tr.	Tr.	117	B
89	C-5	—	—	92	F
5	D-4	—	—	140	B
45	D-10	Tr.	Tr.	99	F

B.S. = Basal surface
C. = Cervical
Cor. Cal. = Corpus callosum
D.T. = Deep temporal
D. = Dorsal
Occ. = Occipital
Par. = Parietal
Prec. = Precentral
Pref. = Prefrontal
S. = Suprasellar
Temp. = Temporal
3rd v. = Third ventricle
Tr. = Traces
W.M. = White matter
* = Cases studied postoperatively.

peak, second peak of equal or greater height, initial fall or "paradoxical" response).

To summarize, Types A, B, and C showed a reduction in the tolerance for glucose and D, E, and F showed an increase; E and F also implied lability and "dysmetria" in the compensatory and regulatory mechanisms.

RESULTS

The results for Groups I and II are tabulated in Tables 1 and 2.

Spontaneous glycosuria occurred unusually in association with supratentorial or spinal lesions, although Case 37 with a bilateral tumor of the prefrontal white matter was a notable exception. On the other hand, in 6 out of 8 cases of space-taking lesions of the posterior fossa there were spontane-

TABLE 2

Glucose tolerance curves after various operative procedures

Case No.	Patient, Diagnosis and Operation	Postop. Day	Glycosuria		Fasting Glycemia	Type of Glucose Tolerance Curve
			Spontaneous	Glucose Tolerance Curve		
66	F.M.T. Schizophrenia Leucotomy	8	—	—	119	C
85	F.M.T.	92	—	—	72	N
74	R.T. Schizophrenia Leucotomy	(Pre-op.)	—	Tr.	70	D
77	R.T.	7	—	—	124	N
81	R.T.	45	—	Tr.	70	N
76	S.S. Schizophrenia Leucotomy	6	—	—	95	B
78	R.S. Schizophrenia Leucotomy	7	—	—	92	B
96	R.F. Psychoneurosis Leucotomy	(Pre-op.)	—	—	113	A
113	R.F.	60	—	—	77	N
114	E.A. Schizophrenia Leucotomy	29	—	—	101	N
115	C.R. Schizophrenia Leucotomy	127	—	—	110	N
68	J.C.F. Idiocy Cingulectomy	(Pre-op.)	—	—	110	N
75	J.C.F	18	—	—	92	N
70	A.L.S. Idiocy Cingulectomy	13	—	—	111	N
6	M.L.G. Right Temporal Lobectomy	10	—	—	95	N
61	M.L.G.	420	—	—	95	N

ous traces of glucose in the urine. Elimination of traces of glucose during the glucose tolerance curve had no major pathological significance. A more abundant elimination occurred in patients with lesions in the following localizations: bilateral prefrontal white matter, prefrontal white matter, temporoparietal white matter, suprasellar and cervical at C1.

Abnormal values of fasting glycemia were found in only 2 instances when

lesions involved the cerebral hemispheres and, with a somewhat greater frequency, when they occupied the posterior fossa or the spinal canal. In 2 cases in which the third ventricle was involved, fasting glycemia was below normal and, in a third case, with a tumor in the same region, it was exceedingly high.

Six patients in Group I exhibited normal glucose tolerance curve. The lesions in these patients were found to occupy the prefrontal (Cases 84 and 107), precentral (Cases 92 and 109), parieto-occipital (Case 26) and ponto-cerebellar (Case 80) regions. The remaining 11 patients with disturbances in the prefrontal, temporal, parietal and occipital white matter and in the prefrontal convexity exhibited diminished tolerance to glucose (abnormally high glucose tolerance curve of types A, B or C). Similarly elevated curves were found on 7 patients with tumors of the posterior fossa. When lesions occupied a region in the vicinity of the hypothalamus, patients so afflicted commonly displayed increased tolerance to glucose (abnormally low glucose tolerance curve of types D, E or F). The area of involvement in these instances was found to be the basal surface and deep substance of the temporal lobes, pineal body, suprasellar region and the third ventricle.

Disturbances of the spinal cord were found to be unassociated with any consistent abnormality of carbohydrate metabolism as manifested by the glucose tolerance curve. In some instances decreased tolerance was found (Cases 56, 72, 54, 5), while in others, curves indicating an increased tolerance occurred (Cases 45, 89, 102).

Prefrontal lobotomy was made in 7 schizophrenic patients in Group II. Glucose tolerance curve was made pre-operatively in 2 cases: in one of these (Case 74), an increased tolerance curve of Type D was exhibited while in the other (Case 96) a decreased tolerance curve was displayed (Type A). Examinations were made in the early postoperative period in 3 leucotomized patients; all of these showed a decreased tolerance to the administration of glucose (glucose tolerance curve Types B and C). In the late postoperative period (after 13 days), glucose tolerance was normal in all of 5 cases tested.

Cingulectomy was performed in 2 idiot children only 1 of whom was tested before operation. The glucose tolerance curve of these patients was normal in each instance. The patient in Group II who had a temporal lobectomy showed no abnormality of her glucose tolerance curve 10 and 420 days after operation.

DISCUSSION

Before entering into a more detailed analysis of a possible relationship between localization of the lesion and the type of curve found to be associated with it, consideration must be given to three hypotheses that, a priori, could conceivably be offered as explanation of the abnormal behavior of the blood glucose regulation mechanisms in these patients. In the first place, Simon and Garvey[35] suggested that reduced tolerance to glucose is somewhat related to emotional tension. In our cases, such tension did not exceed that

displayed by ordinary hospitalized patients; moreover, if responsible, tension should modify curves of all groups in a similar manner. Secondly, the lack of relationship observed with the histopathological identity of the lesion is against the possibility that the pathological process itself produces a hypothetical substance which, passing into the blood stream or the cerebrospinal fluid,[24] modifies carbohydrate metabolism. Finally, it has been proposed that a generalized rise of cerebrospinal fluid pressure followed by a compression of the whole central nervous system, in cats, raises the sugar content of the blood.[38] In our series, no relationship existed between intracranial pressure and the glucose tolerance curve. Opposing any of the general hypotheses postulated above was the fact that the glucose tolerance curves associated with lesions in similar areas of the cerebral hemispheres were usually comparable but differed strikingly from patterns found to arise in patients with disturbances confined to certain other regions (e.g. diencephalon) of the central nervous system.

Information concerning the effect of the cerebral hemispheres in the glucose tolerance curve is available from patients with brain tumors and with lobotomy. As the lesion created by lobotomy is more precise than that represented by tumor, the influence of such excisions on carbohydrate metabolism would be expected to be more easily analyzed. Nevertheless, experimental data that have accumulated on glucose regulation after frontal lobotomy are somewhat conflicting. Kennard, Hampel and Willner[22] reported that lobotomized cats (exhibiting sham rage reaction) showed a transitory hyperglycemia, while similarly prepared monkeys (not showing sham rage) did not display abnormal glycemia. In man, Eringa[12] found a diminished fasting glycemia after a similar operation. Sweet *et al.*[36] described a very marked hyperglycemia in 1 lobotomized patient but it was found that this individual had a hyalinized pancreas.

Our observations are based on experiences with 7 lobotomized patients (Table 2) who were operated on for psychotic disorders. Two pre-operative examinations tend to confirm Simon and Garvey's[35] statement that chronic schizophrenics commonly exhibit abnormal glucose tolerance curves and, in 3 other instances, it can be seen that the abnormality may persist throughout the early postoperative period. Contrastingly, it is evident that, in every instance, tests made 2 weeks or longer after operation showed normal curves. Two patients who had cingulectomy and 1 who had a temporal lobectomy displayed no abnormality of glucose metabolism. From these few observations, the impression is gained that frontal lobotomy, cingulectomy or temporal lobotomy do not adversely influence the glucose tolerance curve. In fact, there is evidence to suggest that if abnormality exists in association with mental disease, it will respond favorably to lobotomy. It is clear, therefore, that large portions of the frontal and temporal lobes can be isolated without inducing prolonged alterations in carbohydrate metabolism.

The responses to glucose administration displayed by patients with tumors of the brain differed markedly from those that followed lobotomy, in that

alteration of the glucose tolerance curve was the rule when neoplastic disease existed. Thus, abnormality was noted in 8 of 12 patients with tumors in the frontal areas, 10 of 10 in the temporal, 8 of 11 in the parieto-occipital and 8 of 8 in the diencephalic region.

Further analysis of the abnormalities exhibited by these patients suggests a rather characteristic difference between responses resulting from lesions of the hemispheres and those involving the diencephalon. In the former instance, decreased tolerance manifestations were almost exclusively seen, while with diencephalic involvement, increased tolerance responses occurred in most cases.

The fact that tumors of the hemispheres, regardless of their location, produced similar changes in glucose tolerance curve (decreased tolerance or hyperglycemic curves) confirms Paleari's[31] observations and suggests that factors influencing carbohydrate metabolism emanate normally from all cerebral lobes presumably. Moreover, cortical areas initiating these influences would seem to be discrete, as surgical isolation of certain regions (frontal, anterior cingulate and temporal) did not produce the same sustained changes in the glucose tolerance curve that the presence of tumors did. It might be supposed that, in the frontal lobe, one of the regions could lie behind the plane of lobotomy. As cortical regions in this and in other lobes of the brain are known to involve autonomic function[21,26,40] (insula, uncus, para-occipital region, superior temporal gyrus, limbic cortex), it would seem logical to suppose that dysfunction of such localized foci is responsible for disturbances in carbohydrate metabolism that attend neoplasms situated throughout the hemispheres.

There is no information from these data concerning the manner in which hemispheral lesions interfere with carbohydrate metabolism. It is possible that the interference could be irritative, abnormal discharges being excited in existing pathways; it is also possible that the interference could be destructive, anatomical connections, whether inhibitory or facilitatory, being sectioned by the tumor. The former possibility could be suggested by Reiss' observation[33] that cortical stimulation in man results in modification of glycemia when an epileptic fit appears. Nevertheless, the latter possibility would seem to be at least as strongly implicated and, at the same time, would be consistent with the observations of Beer and Richard[3] and Bulatao and Cannon[8] which indicate that the neocortex inhibits the reactivity of subcortical autonomic centers, for decorticate animals exhibit higher levels of fasting blood sugar and more marked increases as excited by body restraint.

In 1940, it was concluded by Long,[27] concerning the hypothalamus, that "a predominant role of the region in this phase of the general metabolism has not yet been proved. The available evidence does not entirely dispose of the possibility that some measure of influence may not yet be found." In this series a most consistent disturbance in carbohydrate metabolism (increased tolerance to glucose) followed tumors in or near the third ventricle or, presumably, the hypothalamus. Such being the case, a brief review of in-

formation concerning hypothalamic influences on glycemia is appropriate. Hypothalamic lesions in animals[2,6,10,19,27] may be followed by: a) tendency to low fasting glycemia, b) increased tolerance to hyperglycemic influences initiated by the administration of glucose, adrenalin or anterior lobe extract, c) diminished tolerance to the hypoglycemic effect of insulin. Electrical stimulation of the same region[16,17,20,27,33] may induce hyperglycemia both in animals and in man, and diencephalo-autonomic epilepsy may include, during fits, an elevation in blood sugar level.[28] Evidence at hand, including that reported in the present paper, still lacks decisively conclusive proof of hypothalamic regulation of glycemia, but, undoubtedly, there exists a certain coherency between the different facts reviewed and the probability that hyperglycemic stimuli may normally be mediated through the anterior hypothalamus.

Glucose tolerance curves like Types E and F ("paradoxical") deserve a special comment. After the administration of glucose, a moderate and transient elevation occurs in Type E that is rapidly overcompensated for by a defectively regulated homeostatic mechanism resulting in a marked secondary hypoglycemia. In the "paradoxical" Type F (initial decrease of glycemia), it is possible that an elevation also occurs but, being of a brief duration, the 30-minute sample shows only the decrease that follows. "Paradoxical" results following the administration of adrenalin have been observed by Paleari[31] and Simon,[34] of insulin by Kroll[23] and of glucose by Balea, Segundo and Mendilaharsu.[1] Similar results have occurred in patients with diseases (multiple sclerosis, encephalitis in the chronic state, Parkinsonism, etc.) that affect the central nervous system in a non-localized manner but in which hypothalamic and/or spinal involvement is in no way improbable. In the present series, examples of this type of altered regulation were found only if the disturbance was located in the proximity of the hypothalamus or at the spinal level.

The effect of lesions in the posterior fossa upon glycemia does not serve to elucidate the as yet unknown pathways or centers involved,[4] but undoubtedly confirms the observations initiated by Claude Bernard and later extended to experimental[30,38] and clinical[31] fields. This information indicates that pathological conditions in the neighborhood of the pons and fourth ventricle are associated consistently with a modification of carbohydrate metabolism grossly similar to that seen in mild diabetes mellitus (glycosuria, hyperglycemia and diminished tolerance to glucose).

Spinal cats, as observed by Brooks[7] and Brobeck,[6] are able to restore their blood sugar as well as normal animals, after 0.5 units of insulin per kg. of body weight injected intravenously. Nevertheless, glucose tolerance curves performed by Chor, Finkelman and Blustein[9] in 25 patients with cervical cord injuries, exhibited abnormal (usually elevated) values that, they suggest, were caused by failure of inhibitory or excitatory impulses reaching the peripheral autonomic systems. As Table 1 shows, the results obtained by us coincide with those of Chor, Finkelman and Blustein.[9]

Though the major importance of the endocrine organs in the control of carbohydrate metabolism is in no way disputed, the trends of modern physiology and the necessities of clinical medicine point to the importance of determining with precision the role of the central nervous system in the regulation of the different components of the internal milieu. We believe that the facts reported in the present paper may contribute, to a certain extent, to a better understanding of the nervous regulation of carbohydrate metabolism in man and, in a gross manner, to the delimitation of the areas involved. A more precise localization and a confirmation or rectification of the interpretations offered will, no doubt, be the outcome of future experimental approaches to a subject in which there still exists a great deal of the "confusion and contradiction" noted by Ranson in 1935.[32]

SUMMARY

1. Glucose tolerance curves were studied in patients presenting localized and verified lesions of the central nervous system.

2. The type of abnormality observed was related to the localization of the lesion but not to its histopathological nature or to the presence or intensity of an increased intracranial pressure.

3. Disturbances in the cerebral hemispheres (prefrontal, parietal, temporal, occipital) resulted in a diminished tolerance to glucose.

4. Lesions in the vicinity of the hypothalamus were usually associated with low values of fasting glycemia and increased tolerance to glucose.

5. Spontaneous glycosuria is frequently associated with tumors of the posterior fossa and tolerance is moderately diminished.

6. Abnormal curves of no fixed pattern are encountered with lesions of the cervical spinal cord.

7. None of the patients subjected to operative procedures (frontal lobotomy, cingulectomy, temporal lobectomy) showed abnormal curves after the operation.

8. Results are discussed in the light of experimental and clinical literature.

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THE SURGICAL TREATMENT OF HEADACHE AND ATYPICAL FACIAL NEURALGIA*

BRONSON S. RAY, M.D.

Department of Surgery, New York Hospital-Cornell Medical College, New York City

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OLIVER WENDELL HOLMES is reported to have said, "If I wished to show a student the difficulties of medical practice I should give him a headache to treat." Headache is probably the commonest discomfort of man and it has attributes that set it apart from pain that occurs in other parts of the body. Its significance is often disguised and its attending distress is out of proportion to the severity of the underlying cause.

The neurosurgeon asked to rule out intracranial disease in patients with headache is soon made aware of the need of a broad understanding of pain about the head. He must recognize that in the majority of instances there is no serious disease present and he must through clinical evaluation weigh the need for more extensive and upsetting investigations.

Perhaps the neurosurgeon's only responsibility is to recognize and treat those whose head pain can be shown to be a symptom of an intracranial space-occupying lesion, a painful neoplasm about the head or neck, or one of the cranial nerve neuralgias. But there is a temptation often to explore the surgical possibilities for the relief of other head pain. Some surgeons are encouraged in this respect by a desire to help the patient, some wish to investigate physiological and anatomical factors, while others are deterred by a cautious or even a cynical attitude regarding the possible benefits of surgery.

It is my purpose to review the possibilities of surgical treatment of a variety of these head, face and neck pains (exclusive of neuralgias and painful neoplasms) based on others' reports, as well as on my own experience and convictions. Put another way, it might be asked: "Is there a surgical treatment for headache?"

The basic aspects of headache can be listed under two headings:[40] the sensitive structures of the head and neck, and their nerve supply; and the mechanisms that produce pain.

All of the tissues covering the cranium are more or less sensitive to pain, but the vascular and muscular structures about the head, face and neck together with the mucosa of the upper respiratory passages are the source of most of the headache problems.

The intracranial pain-sensitive structures include the arteries at the base of the brain, the dural arteries, parts of the dura mater in the floor of the

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skull, the venous sinuses and their venous tributaries and nerves possessing pain afferents, namely, the 5th, 7th, 9th and 10th cranial and the first two or three cervical nerves.

The common mechanisms of pain are related to traction and distention of the blood vessels; inflammation of any of the pain-sensitive structures; pressure on pain afferent nerves, and sustained contraction of muscles about the head and neck.

In prolonged vascular headache edema occurring in and about the walls of small vessels causes considerable reduction in pain threshold of these tissues. Likewise in sustained muscle contraction local metabolic changes take place that result in tender areas. Not infrequently vascular and muscular headache exist simultaneously.

HEADACHE AND DISEASES OF THE EYES AND UPPER RESPIRATORY STRUCTURES

It is relatively uncommon for headache to result directly from diseases of the eyes and upper respiratory structures. While inflammation of the mucosa of the nose and paranasal sinuses may result in a mild form of pain in the local regions of the head and face, much of the headache attributed to diseases of these structures is caused by secondary sustained contracture of muscles of the head and neck.[32] Similar principles obtain in headache associated with diseases of the eyes and of their intra- and extra-ocular muscle functions.[14]

MIGRAINE AND OTHER VASCULAR HEADACHES

Dilatation and distention of the arteries inside and outside the cranium give rise to numerous sensory experiences but the interest of the patient and physician is usually directed to the pain that occurs. The location, duration and intensity of the pain vary widely from person to person and in the same individual at different times. The term migraine is reserved by some for a special pattern of headache and associated phenomena, but the line of distinction with other vascular headaches is arbitrary and unimportant.

The detailed studies of migraine leave no doubt that the extracranial branches of the carotid arteries are involved principally. In addition, it seems likely that the meningeal arteries, principally the middle meningeal, take part in the production of the pain, but the intradural vessels seem to play little if any role in this type of headache. It is a common observation that obliteration of the lumen of the offending superficial arteries and even of the carotids in the neck by local pressure will give temporary relief.

Both Cushing[9] and Gordon Holmes[25] remarked on the benefits sometimes observed in migraine patients after subtemporal decompression. Explanation seems to lie in the fact that in the operation both the temporal and middle meningeal arteries are usually divided. Dickerson[12] in 1933 reported the relief of migraine in some subjects by deliberate ligation of the middle meningeal artery.

In our initial investigation of headache mechanisms at the New York Hospital[53] segments of the supra-orbital, temporal, occipital and middle meningeal arteries were resected alone or in combination in a series of patients. While the intensity of the pain was diminished in most, the beneficial effects lasted no longer than 6 months. When we have occasionally been led to try this method since then for the more intractable cases of vascular pain the results have usually been disappointing. The rich anastomotic supply of small arteries, the overlapping and the regeneration of afferent nerve supply amply account for the limitations of the use of this method of treatment.

However, there are reports published and unpublished of the rather common use of resection and ligation of extracranial arteries in the treatment of migraine. Watts, Wiley and Groh[51] had 5 patients relieved of migraine 16 to 24 months after resection of one or more scalp vessels, but did not say what part of their total experience was represented by these cases. Haynes[24] reported 87 per cent relief of cephalalgia after resection of temporal and middle meningeal arteries and avulsion of the occipital nerve; whereas Rowbotham[43] cited 76 per cent failure to relieve headache in a similar series.

About 20 years ago Dandy,[11] Craig,[7] and Love and Adson[31] each reported a few cases of unilateral headache possibly relieved by cervicothoracic ganglionectomy, and the operation has been proposed from time to time since. While reasoning would suggest that the vascular changes in headache may somehow implicate the sympathetic system, it does not follow that cervical sympathectomy will alter the tone or interrupt afferent pain fibers of the vessels concerned in vascular headache, at least in sufficient degree to have value. Smithwick and Simeone[52] disclaim any benefit from cervical sympathectomy for headache while Rowbotham[43] labeled his results in 20 cases as "capricious" and largely unsatisfactory. In my experience I have not found cervical sympathectomy to be a useful procedure for relief of headache, but I have always been intrigued with the possibility that the explanation for improvement in headache in some hypertensive patients after thoracolumbar sympathectomy might be compensatory increase in the tone of cranial vessels.

The more direct approach to surgical relief of vascular headache (exclusive of the neck and lower face) would be interruption of the trigeminal nerve for frontoparietotemporal pain and of the upper cervical nerves for occipital pain since the pain fibers of both intra- and extracranial arteries above a line from the eye to the foramen magnum traverse these nerves. In the case of occipital headache there is perhaps no objection to the interruption of the occipital and postauricular nerves, or even of the upper cervical roots, as a therapeutic trial but I suspect the results would not be very impressive in a follow-up study on a series of cases large enough to have statistical significance. Interruption of the supra-orbital nerve together with resection of the supra-orbital artery has in my hands given disappointing results.

In a few cases reported by Harris,[23] Penfield and McNaughton[35] and Rowbotham[43] beneficial results followed partial section of the trigeminal root.

Love and Adson[31] commented on occasional relief of migraine in patients having had trigeminal rhizotomy for tic douloureux. I have made similar observations in about a dozen cases but I encountered a miserable failure in the one case in which a total trigeminal rhizotomy was deliberately performed for persistent hemicrania. There must be few patients whose headache would justify complete trigeminal rhizotomy with its attendant corneal anesthesia, possible dysesthesias and with the chance of failure to relieve the headache.

Tractotomy of the descending trigeminal fibers in 13 patients suffering from migraine was reported by Olivecrona.[33] In 2 cases the headache was bilateral and the operation was performed bilaterally; one of these patients continued to have occasional headaches of less severity, while in the other there was no relief. In 3 of the unilateral cases headache developed on the opposite side. He estimated the results as satisfactory in about half of the cases, though some discomfort persisted in most, and concluded that the results of tractotomy in migraine can hardly be said to be brilliant. Perhaps one reason for indifferent results is that analgesia after tractotomy is relative and almost never absolute.

Summarily it can be said that in migraine it may be justifiable to try the effects of interruption of the various extracranial and middle meningeal arteries and their accompanying nerves in selected cases. But the expected results will fall short of what may be hoped for and good initial results will often be temporary. Other types of operation are usually unsuitable either because they are ineffective or because they may be attended by complications unacceptable in exchange for migraine.

ATYPICAL FACIAL NEURALGIAS

There is a variety of syndromes of face pain which, although they differ from migraine in location, timing and associated phenomena, are believed to be akin to migraine in that the mechanism of pain is principally arterial distention. Included in this group are: sphenopalatine neuralgia or Sluder's headache, vidian neuralgia, buccal neuralgia, Horton's cephalalgia, lower-half headache, atypical facial neuralgia and carotidynia. There are others with less commonly mentioned names. Each of these syndromes has some special feature which supposedly sets it apart from the other, but each borders on the other and distinguishing features are frequently spurious.

The interest in the sphenopalatine ganglion syndrome,[13,45,50] as well as the opinions of its validity, have waxed and waned for years. The principal objections to the sphenopalatine as well as to the vidian neuralgia are: the lack of evidence that the implied disease of nerves actually exists; and, the similarity of these syndromes to other facial pains that are more readily identifiable as the effect of arterial distention. Lewy[30] in an anatomical study of the nerves concluded that the vidian nerve has no afferent pain fibers and that in presumed transnasal cocainization of the sphenopalatine ganglion usually the maxillary nerve above is anesthetized.

Poe[37] described 4 cases in which he had excised the sphenopalatine ganglion by way of a transantral approach for relief of facial pain. Since the ganglion and the maxillary nerve lie in approximation to each other the operation simultaneously removed the ganglion and a section of the maxillary nerve. Good results were reported in all patients within the limit of the longest follow-up, which was 9 months. From the description, it appears that in 2 and possibly 3 of the cases the diagnosis was trigeminal neuralgia in the maxillary region and good results, therefore, could be attributed to division of the maxillary nerve. Grant,[19] who has performed the operation in several cases, expressed his belief that any benefit is attributable wholly to division of the maxillary nerve. In the one case in my experience any relief of pain was overshadowed by complaints of dysesthesias in the anesthetic area.

Atypical facial neuralgia is a name employed by Frazier and Russell[16] to differentiate from tic douloureux the many other kinds of facial pain. In at least one-third of patients referred to me by physicians for tic douloureux the diagnosis was erroneous. But there is some room for charity in the matter since I suspect the majority of neurosurgeons have at one time or another found to their sorrow that they had misjudged the nature of a facial pain. In a review of the cases at the University of Pennsylvania Hospital, Glaser[18] reported that during a period when 1200 major trigeminal neuralgias were treated there were 245 examples of atypical pain. In these a great variety of surgical treatments, some 292 procedures in all, were unsuccessfully employed. Included in the treatment were trigeminal rhizotomy (11 cases), cervical sympathectomy, periarterial stripping, supra- and infra-orbital nerve avulsion and various ear, nose, throat and dental operations; all were declared a dismal failure.

Further consideration was given to the problem by Temple Fay,[15] who performed various combinations of resection of sympathetics, cervical and cranial nerves and of vascular sheaths (19 cases.) He concluded that pain pathways for blood vessels of the neck and face traversed the trigeminal and vagus nerves. But he recognized the likelihood of pathways in the 7th, 9th, 10th and possibly the 11th and 12th cranial nerves, but excluded the cervical sympathetics.

The exact sensory supply of the arteries in the neck and face is still not established but the likelihood of controlling pain from these vessels by interruption of appropriate nerves with any simple or practical operation is remote.

An occasional report has been made of beneficial results of ligation, resection or perivascular stripping of the external carotid artery or its branches for "buccal" pain[41] and of the carotids for carotidynia. In 6 cases I found operations on the external carotid and maxillary arteries not to be helpful for facial pain while in 4 cases of carotidynia[6] perivascular stripping gave partial relief in 2 and no benefit in 2 others.

A particular pain syndrome originally described as erythromelalgia of the head (by Horton, MacLean and Craig[26]) but lately known as Horton's

cephalalgia has caught the fancy of neurosurgeons. Horton[27] has implied that histamine somehow plays a role, but this pain may well be one variant of vascular pain in the orbitofacial region.[53]

It was suggested by Gardner and associates[17] that the syndrome might be in the nature of a greater superficial petrosal neuralgia, or at least that division of this nerve might be helpful. In 13 cases of orbitofacial pain he divided the greater petrosal nerve and in 2 of these the operation was bilateral. Results were reported as excellent in 25 per cent, fair to good in 50 per cent and a failure in 25 per cent. The same operation in 13 additional patients with miscellaneous head pains produced good results in 3. The complications listed were: temporary loss of tearing, crocodile tears, Horner's syndrome, painful keratitis and facial paralysis.

It is interesting that Gardner postulated benefit on the basis of interruption of vasodilator nerves and disregarded the possible effect of dividing afferent fibers that traverse the nerve. Sweet and White[48] reported that stimulation of the central end of the divided greater superficial petrosal nerve caused pain and 3 of their patients were relieved of pain by petrosal neurectomy, while 2 were not.

The operation has been performed by others[2,49] including myself but the results to me do not seem to be impressive. When it is considered that many aspects of the pain for which the operation is employed are not well understood, the incidence of early relief is less than 50 per cent, recurrences are known to take place and certain complications are not readily acceptable, there is not enough to justify enthusiasm for the procedure.

OCCIPITAL AND SUBOCCIPITAL PAIN

Pain in the occipital and suboccipital regions results from three types of mechanism which may occur alone or in combination: (1) muscle tension, (2) vascular distention and (3) irritative conditions of the sensory nerves, roots or spinal ganglia in the upper cervical region.[53]

A revival of interest in posterior headaches has occurred probably as a result of greater awareness of cervical disk pathology. Raney and Raney[38,39] concluded that cervical disk lesions commonly result in occipital, frontal and temporal headaches. They found it impossible to determine a direct neural connection, but suggested that diffusion would explain the phenomenon. Yet they reported that head pain caused by cervical disk disease was not relieved by section of the sensory root of the 5th nerve or by trigeminal tractotomy; also that cervical sympathetic block did not affect the headache unless the procaine infiltrated the neck muscles.

It has been shown that sustained cervical muscle contraction occurs as a protective mechanism accompanying a painful lesion at any level of the cervical spine and that the muscle contraction here not only is locally painful but may induce muscle contractions and changes in vascular tone in other parts of the head and face.[44] In support of this is the common experience that headaches related to tonic states of the cervical muscles can usually

be relieved by muscle-relaxing agents such as local heat, massage, curare, traction or procaine infiltration. Injection of hypertonic saline into occipital muscles consistently causes pain not only locally but in more remote regions of the head and face. Conversely, pain thus induced may be terminated by local infiltration with procaine.[5,10,44] Resection of occipital and postauricular nerves is occasionally of temporary benefit, but has obvious limitations.

Hunter and Mayfield[28] reviewed their experience with 11 cases of pain in the head and face attributed to upper cervical root disease, presumably secondary for the most part to trauma of the upper cervical spine. The pain was characterized by its appearance in bouts, initiated in the suboccipital region, radiating to the vertex, temple, orbit and sometimes the lower jaw; usually it was unilateral. They found that stimulation of the 2nd cervical root produced pain in the vertex and region of the eye, while stimulation of the 3rd root referred pain to the region of the ear and neck. Treatment in their 11 cases was either by (1) avulsion of the greater occipital nerve, (2) intraspinal section of the sensory root C_2, or (3) section of sensory roots C_2 and C_3. Eight of the 11 patients were benefited by the operations.

Hence, it should be recognized that pain having its origin from structures in the cervical and occipital regions may appear simultaneously in the forward part of the head and face. Operative treatment is usually not required for relief of pain of occipital origin with the possible exception of those few patients who have convincing evidence of disease of the upper cervical spine and nerve roots in which case upper cervical rhizotomy may be useful. Section or avulsion of nerves in the occipital region is technically simple and harmless, said to be useful for a variety of persistent occipital pains but initial beneficial results have frequently been temporary.

POST-TRAUMATIC HEADACHE

None of the problems pertaining to headache supersede those that follow head injury. The incidence is one-third to one-half in those patients with head injury sufficient to bring them to a hospital. Trauma to pain-sensitive structures of the head provides ample reason for head pain and the persistence of an extradural or a subdural hematoma may be a source of headache in the early period up to some weeks. However, in most cases there is no convincing evidence that pathologic changes of any kind occur to perpetuate head pain beyond this period.[4]

In 1936 Penfield and Norcross[36] concluded that a cause of chronic posttraumatic headache might be found in the formation of dura-arachnoidal adhesions and that effective therapy might be provided by introduction of subdural air. A follow-up study 8 years later by Ross and McNaughton[42] concluded that there had been few patients who had remained cured after this procedure and in these few it was believed that other factors had played an important part.

Painful scars of the scalp which may be a source of noxious stimuli can sometimes be revised to advantage and in those patients with complaint of

headache accompanying cranial defects about half are relieved by cranioplasty.[21] But surgeons are well acquainted with the frequently disappointing results of revising painful scars anywhere over the body.

PAINFUL DYSESTHESIAS OF CRANIAL NERVE LESIONS

Under the heading of painful dysesthesias of the cranial nerves several could be mentioned, but there are two conditions in particular that concern us. While they do not fall exactly in the category of the other types of head pain under discussion there is much in common, particularly in the matter of refractoriness to surgical treatment.

One of these is the postherpetic pain which occurs particularly in the forehead region of elderly patients and which dominates their waning years of life. Any notion that the disease in these patients is limited to the Gasserian ganglion is soon dissipated when it is discovered that division of the sensory root or of the tract in the medulla provides little, if any, relief.[34] I have tried rhizotomy in 2 patients and tractotomy in 2 others without the slightest benefit. Avulsion of the supra-orbital root because it is simple and safe has often been employed, but usually with disappointing results. The same is true of cervical sympathectomy and of incision for undermining and isolating the painful area, though there have been verbal reports that the latter is sometimes helpful.

The story is perhaps best told in a report by Sugar and Bucy.[47] In a patient with postherpetic pain in the eye, cheek and nose the following methods were used in sequence with appropriate lapses of time to evaluate results: (1) injection of alcohol into the infra-orbital nerve, (2) roentgen radiation of the Gasserian ganglion, (3) partial division of the sensory root of the trigeminal nerve, (4) total section of the sensory root, (5) cocainization of the sphenopalatine ganglion, (6) procaine block of the stellate ganglion, (7) excision of the contralateral sensory cortex for the face, (8) excision of the ipsilateral sensory cortex for the face, (9) a series of electric shock convulsions and (10) bilateral prefrontal lobotomy. The evaluation of the result was that the patient still suffered from the pain though it was not as troublesome as it had been.

Wycis[54] has informed me that mesencephalotomy in 3 cases of postherpetic pain in the face has proven satisfactory in 2 cases and failed in 1. We must hopefully wait for final confirmation of the effectiveness of this method of treatment.

The other variety of painful dysesthesia is one that particularly plagues the neurosurgeon. It occurs following trigeminal rhizotomy or tractotomy for tic douloureux. Fortunately the severe form occurs in only about 5 per cent of cases but in these it is an endless source of annoyance. Sympathectomy is of no value. A few reports of the use of lobotomy for the most part indicate failure or equivocal results. In my experience with 2 cases bilateral lobotomy was not helpful. Spiegel and Wycis' report[46] of the use of mesencephalotomy in 3 cases indicates beneficial results at least in 2.

The simple fact is that the treatment of painful dysesthesias of the face is one of the most discouraging chapters in the chronicle of neurosurgery.

GENERAL COMMENT

Psychosurgery seems not to have been much employed for headache and atypical facial neuralgia; it is mentioned only briefly and without enthusiasm in a few reports that have come to my notice.[22] An interesting comment which perhaps has an indirect bearing on the subject was made in the report of the large Boston Psychopathic Hospital series.[29] It was suggested that in some of those with chronic postlobotomy headache the cause lay in meningocortical scarring resulting from the incision. Though it is very questionable whether headaches occur on this basis the fact remains that some patients do have severe headaches after lobotomy.

With regard to the useful application in various forms of head pain of thalamotomy by stereo-encephalotomy we must for the present depend on the judgment of those few who are skilled in the use of the instrument. Dr. Bailey's tacit comment[3] on the subject is that "others had better wait until the technic is better established before attempting to make destructive lesions in this concentrated region. After several years of investigation the editor has not yet dared to attempt it."

And finally a comment on the use of anesthetic blocking or injection methods for the relief of pain is perhaps not out of order. The simple faith that most patients and many doctors have in the ability of a "skilled technician" to control pain with a well-placed injection is disturbing. Neurosurgeons in particular are exposed to this flattering confidence and some are vulnerable. But no one is in a better position than a neurosurgeon to know the limitations of the method as well as the complications that may attend it. At best, procaine or newer, longer-lasting local anesthetic agents provide but brief benefit. Alcohol blocks of the trigeminal nerve may be of use at times, but as experienced a surgeon as Grant[20] reported a disturbing number of difficulties with the procedure even in his hands. The report of Ochsner and associates[1] on 14 deaths and other complications from what is commonly believed to be an innocuous injection of the stellate ganglion is an occasion for considerable concern.

Neurosurgeons instead of trying to live up to the expectations of their patients and colleagues in the use of injection methods for the relief of pain can do much to clarify the matter by pronouncing its limitations and risks.

CONCLUSION

In conclusion I should hardly like to take the position that all possibilities for the surgical treatment of headache have been exhausted though the very nature of the varieties of head pain that have been discussed does not encourage hope in the solution of the problem through surgery. There is probably no harm and maybe occasional benefit in the judicious use of an operation performed as a therapeutic trial but the indiscriminate use of

operations on patients, many of whom have prominent emotional disorders, is out of keeping with the sound principles that characterize most of the rest of our neurosurgical effort.

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SOME COMPLICATIONS OF VERTEBRAL ANGIOGRAPHY

OSCAR SUGAR, M.D., AND PAUL C. BUCY, M.D.

Department of Neurology and Neurological Surgery, University of Illinois College of Medicine, and Department of Surgery, Northwestern University Medical School, Chicago, Illinois

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As THE use of cerebral angiography has become widespread, there are increasing numbers of case reports of complications.[7,8,10,11,13,15] These are most valuable in trying to set standards for selection of patients for this diagnostic procedure. The similar stories from the 3 cases reported here are intended for this purpose.

CASE REPORTS

Case 1. H.W., 48 years old, a doctor's mother, had "migraine" attacks for several years beginning at the age of 28. The severe left-sided headaches were preceded by blurred vision and numbness in the right hand. Six months prior to entry in St. Luke's Hospital, there was return of severe left frontal headache following blurred vision; the pain lasted 6 to 12 hours, and recurred every week or two. Two weeks prior to admission, there was numbness and tingling of the right hand. A few days later, the usual headache began, but the blurred vision persisted when the headache disappeared.

Examination. On admission on Nov. 27, 1948 there was a complete right homonymous hemianopsia (without macular sparing). Right biceps and knee reflexes were slightly increased. Ankle reflexes were equal. There was no other neurological disturbance. Findings on lumbar puncture were normal. Roentgenograms of the skull showed a midline pineal calcification. B.P. was 144/98.

Angiography. Because of the possibility of aneurysm, left carotid and left vertebral angiograms were done with 35 per cent Diodrast (iodopyracet) under general anesthesia. Unfortunately, the total quantity of Diodrast was not noted.

Course. The patient was returned to her room in good condition, with B.P. 128/90. Two hours later, at 4:30 P.M., she was still unconscious; B.P. was 186/110, and pulse was irregular in quality and at a rate of 84 per min. At 8:00 P.M. she moaned and moved her arm occasionally. At 3:00 the next morning, the pulse rate was 100, respiratory rate 30, and B.P. 172/112. At 5:00 P.M., the B.P. suddenly dropped from 164/112 to 110/38; pulse 100, respiration 40. At 5:27 she was turned on her back; pulse 80, respiration 20 and very shallow. Two minutes later, she stopped breathing. There was a poor pulse at 70 per min. In spite of oyxgen, coramine and artificial respiration, she died.

The left carotid angiograms were normal. The vertebral angiogram (Fig. 1) shows a number of filling defects in the vertebral and basilar arteries typical of arteriosclerosis. Marked resistance to flow because of arteriosclerosis could explain the discontinuities in the posterior cerebral circulation.

Autopsy (Dr. Edwin Hirsch, Department of Pathology, St. Luke's Hospital).

There was an old liquefied infarct of the calcarine area of the cerebrum. There were marked atheromatous changes in the basilar vessels. The left vertebral artery was occluded for 0.8 cm. by an old atheromatous plaque in the distal 1 cm. before its junction with the right vertebral artery.

Histologic study confirmed the ancient nature of the softening and there was hyalinization of small vessels in this area.

FIG. 1. *Case 1.* There are small irregularities of filling of the vertebral artery. The distal end of the basilar artery is spotted with dye. There is marked discontinuity of dye between the beginning of the posterior cerebral arteries and the venous filling in the occipital and posterior cerebellar regions, indicating slowed circulation.

Case 2 (Research and Educational Hospital No. 405–635). L.M.B., aged 69, had onset of generalized epileptic seizures, midfrontal headaches, and disturbances of memory 1 year before hospitalization on Aug. 22, 1953.

Examination. The patient was an obese woman who was occasionally confused. B.P. was 186/136 mm. Hg. Retinal arterioles were "silver-wired." There was a grossly evident left homonymous hemianopsia and depression of visual acuity (unable to count fingers at 6 feet). The deep tendon reflexes in the left leg were increased and a Babinski sign was elicited on this side. Blood count and urinalysis were normal. Spinal puncture yielded clear fluid with 51 mg. protein, under normal pressure. X-rays of the skull were normal but chest films showed a mediastinal widening suggesting neoplasm. Metastatic intracranial neoplasms were suspected.

Angiography. An intravenous test dose of Diodrast 35 per cent was well tolerated so the patient was anesthetized and intubated. The right vertebral artery was injected with three 10 cc. portions of Diodrast, and when no mass lesions were seen, a single 10 cc. injection was made into the right carotid artery. No mass lesion was

found. The endotracheal tube was removed 75 minutes after induction of anesthesia (pentothal, nitrous-oxide-oxygen, and trichlorethylene). At this time she responded to painful stimuli, but 20 minutes later she did not, although the B.P. was 160/110 and the color was good.

Course. At 3:30 P.M., the pressure was 146/100 and the color was good. She was found dead 20 minutes later.

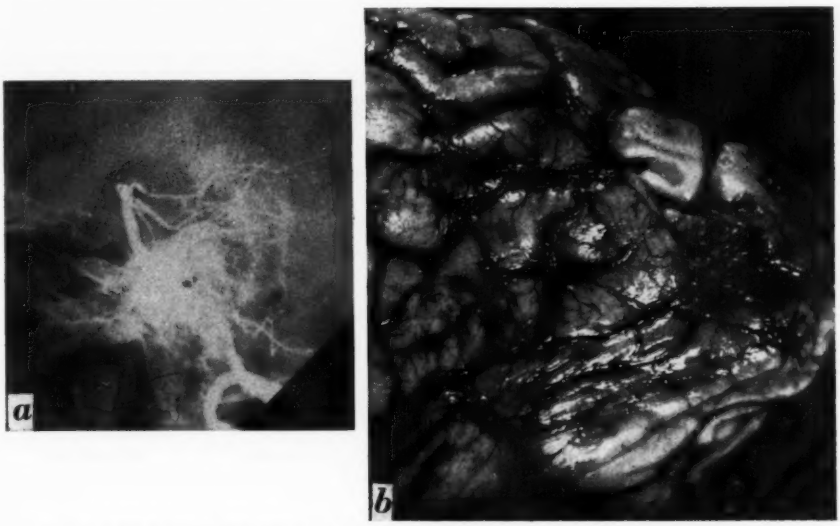

FIG. 2. *Case 2.* (*a*) Beside the small filling defects in the vertebral and basilar arteries, there are marked indentations of the posterior cerebral and superior cerebellar arteries at and just beyond the greatly constricted bifurcation of the basilar artery. (*b*) Medial surface of the right occipital pole, showing shrunken, scarred area of old encephalomalacia responsible for hemianopsia.

Review of the axial and lateral angiograms (Fig. 2*a*) shows mural filling defects in the basilar artery, which is otherwise of good caliber. However, the superior cerebellar and posterior cerebral arteries appear very small, and there are marked constrictions at their origins.

Autopsy showed generalized arteriosclerosis (especially severe in the brain and heart), atherosclerosis of the aorta and its major branches, and right and left ventricular dilatation. In the brain all large vessels showed atherosclerosis. This was especially marked in the vertebral, basilar, and posterior cerebral arteries. Cross-sections of the posterior cerebral and superior cerebellar arteries showed marked narrowing of the lumina (corresponding to the thin column of contrast material in the angiogram). There was no evidence of antemortem thrombosis, at least at the origins of these vessels. There was marked softening of the inferior aspect of the temporo-occipital area bilaterally. This was more marked on the right, where it extended to the tip of the occipital pole (Fig. 2*b*). Another small softening was found in the right internal capsule and caudate nucleus.

Histologic study showed that the area of encephalomalacia in the right occipital

lobe had progressed to a precystic stage. Evidence of arterial and arteriolar arteriosclerosis was everywhere apparent, and in the basal ganglia there was actual necrosis of vessel walls. A section of the basilar artery showed calcific plaques, splitting of the elastic media and necrosis of all the vessel layers.

Case 3 (Chicago Memorial Hospital No. 134894).* M.M., a woman, was born in 1897. During the 8th month of her third pregnancy (1919) she suddenly fell, was unconscious and subsequently had a right facial weakness. Blood pressure was said to have been very high, and there was albuminuria. However, this child and a fourth were born without further incident. In 1941, she complained of headache, weakness and dizziness. In spite of several thorough investigations at various hospitals and clinics, nothing abnormal was found until after severe headache, vomiting and semistupor developed on Nov. 26, 1943.

On Dec. 3, 1943, she was hospitalized and, following ventriculography, a large midline meningioma arising from the under surface of the tentorium was removed. On the 11th postoperative day, the patient having hitherto done quite well, difficulty in speaking developed, which led to a severe expressive aphasia within the next 24 hours. She was unable to write, although she could read. Pressure of the spinal fluid was 35 mm. of clear yellow fluid. About a week later, the aphasia began to improve and by the time of discharge, Dec. 24, 1943, it had disappeared.

She remained well thereafter until 1952, when bitemporal pain and generalized headaches appeared, relieved by aspirin. These persisted into late 1953. Examination by an opththalmologist in September, 1953 revealed left homonymous hemianopsia with macular sparing. The headaches diminished, but the visual loss persisted, and she was hospitalized on Dec. 9, 1953.

Examination. X-rays of the head showed no abnormalities except the surgical defect in the occipital bone. B.P. was 124/78. There were no abnormal neurological findings aside from left homonymous hemianopsia.

Angiography. On the next day, under intravenous sodium pentothal anesthesia and intranasal administration of oxygen, three injections of 6 cc. each of Urokon (35 per cent) were made into the right carotid artery. No abnormalities were seen, so 10 cc. of Urokon were injected into the right vertebral artery. The artery could be followed only to the foramen magnum (Fig. 3). Because of the belief that the exposure had been made too soon, subsequent injections of 10 cc. and 6 cc. were made, but the resulting films were unchanged.

Course. Three hours after completion of angiography, the patient was awake and responding well. Seven hours after angiography, she became lethargic, but could move all extremities on request. B.P. was 110/70 mm. Hg, pulse rate was 54 per min., and she vomited on several occasions. An hour later, the right pupil was found to be larger than the left, but both reacted well to light.

On the following morning, she was still lethargic and the right pupil was still dilated. Lethargy increased and on December 12, the speech was slow and unintelligible, and at times she would not respond when spoken to. Pulse varied from 48 to 62 per min., B.P. from 118–140/55–75, and respirations 18–20 per min. When examined at noon on this day, she had a complete right 3rd nerve palsy and left Babinski sign; there was a questionably positive right Babinski sign as well. She became less stuporous and at 12:30, 10 cc. of 1 per cent procaine were injected for a right stellate ganglion paralysis. This was produced, and within 15 minutes, she was talking coherently. That afternoon she was alert and asked for food. By the

* Case history of meningioma previously reported by Russell and Bucy.[14]

FIG. 3. *Case 3.* Spotty configuration of dye in the basilar artery is associated with marked narrowing at the 2nd cervical level. The dye could not be visualized above the transverse process of the atlas in any of the three films taken.

next day her pupils became equal and only a slight right ptosis remained.

On Dec. 15, 1953, she was found to have a left homonymous hemianopsia. The right pupil was smaller than the left, there was a slight right ptosis, and the right side of the face was slightly drier than the left.

On December 16, she was discharged to take Papaverine (0.1 gm.) four times daily. She has continued well except for persisting left homonymous hemianopsia. This is now attributed to thrombosis of the right posterior cerebral artery, and it is believed that she also has a partial occlusion of the right vertebral and basilar arteries.

Probably the most important lesson to be learned (or relearned) from these cases is that cerebral angiography is not without hazard, and Diodrast and Urokon are not innocuous materials. The most puzzling aspect of the problem of complications of angiography is the wide divergence in incidence in different clinics. This must be because of differences in technic (unless there is some hidden factor in the genetic make-up of different national groups). Among these must be included the different contrast media used, the quantities of dyestuff, the timing of successive injections, and the type of anesthesia. Most of the reports of low incidence of complication come from the Scandinavian countries, where Umbradil and Perabrodil are used. These, like Diodrast, are solutions of various salts of crystalline iodine compounds (3,5 diiodopyridone-N-acetic acid). It is not probable that it is the

sodium or diethanolamine salts that are responsible for the differences. It does appear that the smaller the total dose of contrast medium used, and the smaller the individual doses for each injection, the less numerous are the complications. However, serious complications have been reported with one 10 cc. injection of Diodrast, and Radner's[12] patient had only 9 cc. of Umbradil. Experimental evidence[2] indicates that a relatively long wait between successive injections is safer than making injections in rapid succession. A minimum wait of 10 minutes has been suggested, during which time it should be possible to examine films resulting from previous injections. If there are signs of vascular occlusion, arteriosclerosis, or marked delays in circulation through the brain, it would doubtless be wise to discontinue the procedure. Decker and Holzer[4] suggest that films always include the tip of the needle, for they believe that injections into the vessel wall or just outside of it can cause such vasospasm as to make repeated injections of contrast material hazardous. (However, there is no evidence of any such complications here.)

Certainly if the injection is done under local anesthesia, and the patient shows an untoward effect of injection (coma, aphasia, hemianopsia, hemiparesis or hemiplegia), further injections are contraindicated. With general anesthesia such warnings pass unnoticed; hence, especial care must be used under these conditions to use small quantities of dye, well spaced injections, and, probably, very small amounts of solution with which to rinse the needle (for it seems likely that with some impairment of blood-brain barrier caused by the contrast medium, injection of large amounts of saline or glucose solution will produce rapid swelling of the brain). However, Perese *et al.*[10] warn that local anesthesia is no guarantee that there will be warning of impending difficulty.

It is not clear just how angiography precipitates the neurological lesions. Thrombosis does not appear to be caused by the procedure. In Case 1, the thrombus in one vertebral artery found at autopsy was old, and no thrombi were found in the other case. Emboli from traumatized intima or from clots forming at the needle tip are unlikely in view of the large-bore needle and the intermittent washing through of small amounts of saline solution. Spasm of major cerebral vessels has been seen in many angiograms but was not evident here. The only obvious factors common to these 3 patients are atherosclerosis, with narrowing of the lumen of major vessels of the vertebral-basilar system, vertebral angiography, and general anesthesia. It is conceivable that the Diodrast could cause enough internal swelling to occlude a channel already narrowed by atherosclerosis. The ischemia (which we assume to be the basic cause of death) may be a relative one, and be caused by lowering of blood pressure during the angiographic procedure under general anesthesia. This hypothesis of relative hypotension has been discussed by Denny-Brown[5] for basilar artery syndromes and by Corday *et al.*[3] for lesions of the cerebral hemispheres.

In all events, the important factor appears to be atherosclerosis of the major cerebral vessels. It is roughly correlated with atherosclerosis else-

where in the body,[6] but can exist independently.[1] Retinal atherosclerosis (histologically proven) means a 4 to 1 probability that the basilar artery is arteriosclerotic, but unfortunately there is no good correlation between the histologic appearance of arteriosclerosis of the retina and this disorder as seen through the ophthalmoscope. Cerebral arteriosclerosis is more apt to be intense and to involve smaller vessels if there is co-existent hypertension, according to Fisher.[6]

It is difficult to select patients for angiography who do not have arteriosclerosis, for many patients with tumors or vascular anomalies also have arteriosclerosis. Age is of little value as a criterion (beyond 40 years certainly); in this series, the patients were 48, 57, and 69 years old. The age span in the group of Perese *et al.* was 42–60, and 3 or 4 injections of 10 cc. of Diodrast were used. One of their patients had multiple metastases, in 1 case no autopsy was performed, and the other 4 patients who died had arteriosclerosis and thrombosis of the cerebral or basilar arteries with extensive softening (including 1 patient only 46 years old). Radner's[12] patient was 66, admitted for right oculomotor palsy. She was known to have arterial hypertension and diabetes mellitus, with diabetic retinopathy. After carotid injection failed to show an aneurysm, one 9 cc. injection of Umbradil into the right vertebral artery filled both vertebral arteries and showed indentations of the vertebral, basilar, and both posterior cerebral arteries. There was no immediate reaction but in 45 minutes the woman became comatose; consciousness slowly returned 10 minutes later, with right-sided weakness, slurred speech, and difficulty in swallowing. In spite of antibiotic and anticoagulant therapy, the patient died on the 11th day. Autopsy showed severe generalized atherosclerosis. Although the lumina were narrowed almost to the point of occlusion, there was no recent thrombosis. Old and recent softenings were found in the left occiput, both thalami, and the rostral part of the brain stem.

In the 162 vertebral angiograms done by Petit-Dutaillis *et al.*,[11] there were 4 serious accidents, 2 of which were fatal. One followed intra-arterial injection of procaine for failure to visualize the intracranial portion of the vertebral artery (and autopsy failed to reveal the pathology). The other occurred in an aged arteriosclerotic patient with right hemianopsia and hemiparesis, who died suddenly after the angiography (which had appeared to go without incident). Sjögren[16] encountered only 1 complication in over 200 percutaneous vertebral angiograms with Umbradil; this was a transient syndrome of posterior inferior cerebellar artery insufficiency.

Occlusion of vessels supplying the brain is being reported with increasing frequency, but it is rare that the vertebral-basilar system is involved. In a large series of angiograms, Decker and Holzer[4] found 97 instances of occlusion of vessels supplying the brain. Only 3 involved the vertebral and basilar system, whereas there were 35 occlusions of the carotid artery in the neck and 7 within the skull. The remaining 52 were occlusions of major cerebral vessels (including 42 of the middle cerebral artery and 1 of the posterior cerebral artery). In one autopsy, there was partial occlusion of the proximal end

of the basilar artery and complete obstruction of a segment of the posterior cerebral artery. Meningeal anastomoses were found in this patient. The authors offer the possibility that anastomoses between the muscular branches of the vertebral and occipital arteries protect the patient against occlusions of the vertebral arteries. Occlusions of the basilar artery are rarely compatible with life, but transient syndromes may be produced by stenotic lesions. Insufficiency of the basilar system may be completely unnoted until occlusion of a carotid artery interferes with collateral flow and precipitates infarction (and, conversely, occlusion of basilar flow may precipitate a middle cerebral artery syndrome if a carotid artery has been closed off some time before[5]).

The cerebellar arteries usually have even better anastomoses than the cerebral ones, so that occlusions (except for the posterior inferior cerebellar artery) are rarely clinically evident. The superior cerebellar artery is rarely occluded, and then usually by embolus. Luhan and Pollack[9] reported 6 cases of this disorder, 3 with autopsy. One was in a woman, 36, who was 7 months pregnant when she had a subarachnoid hemorrhage. Signs of posterior fossa involvement developed and a vertebral angiogram was done. It was normal. After she awakened from the anesthesia, she went into labor, had a major seizure, and aspirated vomitus. She died 24 hours after the arteriography. Autopsy disclosed a hemorrhagic softening in the mesencephalon, ascribed to a soft clot in one of the major subdivisions of the superior cerebellar artery. This was believed to have been caused by an embolus (site not disclosed by general autopsy).

Perhaps it would be wise to be especially cautious in patients with homonymous hemianopsia whose spinal fluid pressure and roentgenograms of the skull are normal. If dye study still appears indicated, and carotid angiography is done without revealing the lesion, it might be best to wait for a few days before doing the vertebral angiogram. In this way, one might avoid impairing the communications from the carotid to the basilar system and permit collateral flow in case there should be vascular insufficiency in the vertebral-basilar system. The vertebral angiography might well be done under local anesthesia providing that this is generously infiltrated into the region (including the periosteum) and providing that the needle for angiography is inserted from medial to lateral and always pointing upward (to avoid the roots of the brachial plexus). After a single injection of 8–10 cc. of Diodrast, the films should be inspected, and if signs of arteriosclerosis or occlusion are found, the procedure had best be discontinued. Measures to increase cerebral blood flow might then be undertaken (if no bleeding has occurred recently within the cranium); systemic or intra-arterial injections of Papaverine, carbon dioxide inhalations, and stellate block all have their proponents.

It might be argued that in virtually every case of complication of angiography because of arteriosclerosis, the procedure has merely hastened the inevitable in a patient who already has serious neurologic disease (else the

procedure would not have been done). However, patients with arteriosclerosis can live with their symptoms for many years before natural processes put an end to life, and we do not believe that curiosity as to the cause of a disorder should be put above considerations of the patient's welfare.

SUMMARY

Death followed vertebral angiography in 2 patients, 48 and 69 years of age, in whom autopsy showed severe arteriosclerosis. In a third patient, aged 57 years, recovery occurred after the procedure had caused marked increase in neurologic symptoms. In each patient, there were headaches, homonymous hemianopsia, and other neurological findings, without evidence of raised intracranial pressure. In each instance, the angiograms revealed evidence of arteriosclerosis of the vertebral-basilar system.

The reduction in incidence of complications of vertebral angiography is discussed, with suggestions to limit the quantity of contrast medium and number of injections, to lengthen the interval between injections, and to look at each film exposed before making more injections.

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TOTAL REMOVAL OF INTRAMEDULLARY TUMORS*

JAMES GREENWOOD, JR., M.D.
Department of Neurosurgery, Methodist Hospital and Baylor University College of Medicine, Houston, Texas

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COMPLETE removal of intramedullary ependymomas has been carried out at times when the tumor was of suitable consistency and when a definite cleavage plane made such removal possible.[1,2,3] Total removal usually leaves some neurological deficit, and in the cervical region may be dangerous. It is felt that the report of 6 cases in which intramedullary ependymomas were removed completely might be worth while, since 3 of the 6 patients apparently have no significant neurological disability.

From the technical standpoint, certain prerequisites seem to be needed for total removal of these usually benign tumors, the most important being (1) that surgery be carried out before paralysis is too far advanced; (2) that the tumor be of such consistency that it can be handled without damage to the cord; (3) that there be a good plane of cleavage between the spinal cord and the tumor; (4) that the multitude of fine, almost invisible vessels which pass from the tumor into the cord, particularly in the region of the central canal, be properly coagulated and cut so that a dry field will be maintained through the procedure (unipolar coagulation is inapplicable in this location while by contrast bipolar, or two-point coagulation, seems to do little, if any, damage, provided irrigation with saline solution is carried out while coagulation is being done); and (5) gentleness that does not exceed the elastic limit of cord tissue. Some tumors have invasive characteristics or their consistency may be such that total removal should not be attempted. Certainly good temporary results can be obtained by partial removal or by simple midline section of the cord with decompression. Removal may be possible as a secondary procedure after a period of waiting which allows the tumor to extrude itself.

CASE REPORTS

Case 1. Mrs. L.R.N., aged 41, was examined on Aug. 13, 1941. Fairly progressive weakness in the legs, beginning 8 months before, had reached the point where she was unable to walk without help.

Examination. Deep reflexes were markedly increased in the lower extremities, bilateral Babinski was present, and there was a transient ankle clonus. There was loss of sensation of pain, temperature, vibration, and stereognosis below the 5th rib, while position sense was fairly well preserved. A Queckenstedt test showed evidence of a partial block, and myelography showed interruption of lipiodol at the level of the superior border of the 7th thoracic vertebra.

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Operation. A laminectomy of C7 and T1–6 vertebrae was carried out, with the dentate ligaments being sectioned on both sides at the level of the 5th thoracic vertebra. The spinal cord was incised in the midline and the tumor was gently dissected out. The vessels attaching the tumor to the central canal were coagulated with two-point coagulation forceps, using saline irrigation for cooling. The dura mater was easily closed.

Microscopic Examination. The tumor was composed of typical ependymal cells with tendency to pseudorosette formation around vascular channels.

Course. Following surgery, her neurological picture was very much worse, although she was able to move her legs slightly within a few days.

During the succeeding several months she was able to walk with help and when examined 1 year after surgery was able to walk perfectly, but was not able to walk more than about a block. Pain sense had entirely recovered except for a small area of hypalgesia in the left leg. Reflexes were approximately normal and there was no bladder disturbance. Two years later she considered herself perfectly well, although she felt that the left leg was not quite normal. Walking did not tire her and there was no limp or spasticity. The patellar reflex was increased on the left. Examination in February, 1954 revealed that she is still quite normal.

Case 2. Mrs. L. McA., aged 46, was examined Nov. 10, 1942. Paralysis of the legs had begun over 3 years before, with numbness in the lower extremities and difficulty in controlling the bladder.

Examination. There was about 25 per cent normal strength in the left leg and about 50 per cent in the right. There was a partial sensory level up to the 2nd rib on the right and up to the 4th rib on the left. Reflexes were markedly increased and a bilateral Babinski sign was present. Myelography showed a block at the level of the 4th thoracic vertebra.

Operation. A laminectomy was done from C6 to T4 laminae inclusive. The spinal cord was divided posteriorly in the midline and the tumor was gently dissected out. Blood vessels connecting the tumor to the central canal were coagulated with two-point coagulation forceps and, after removal, the cavity which extended from the 7th cervical vertebra to the upper portion of the 4th thoracic was clean and there was no evidence of contusion.

Microscopic Examination. The tumor was a typical ependymoma with pseudorosette formation about the tissue spaces and vascular channels.

Course. Following surgery, the patient had only slight movement in the right leg. Unfortunately, a fulminating pneumonia developed, complicated by delirium tremens, and she expired on the 5th postoperative day.

Autopsy showed that the spinal cord was in good condition with no evidence of contusion or swelling. The history of alcoholism was obtained only after toxic symptoms appeared.

Case 3. Father T. McG., aged 39, was examined July 2, 1952. He complained chiefly of throbbing pain in the right arm and hand, present for 12 years. In 1949 the right scalenus anticus muscle had been sectioned at a clinic out of the State. For 2 years he had had considerable difficulty in walking.

Examination revealed analgesia in the cervical 5th, 6th, and 7th dermatomes on the right and in the 5th and 6th dermatomes on the left. There was marked stiffness in walking, reflexes were increased in the lower extremities, and spasticity was definite in both legs. Myelography showed a block at the 4th thoracic level.

Operation. A laminectomy of C5–7 and T1 vertebrae was carried out. A midline incision was made and the enlargement of the cord, about 4 to 5 cm. long, was incised down to the tumor, which was removed piecemeal. This was a soft, red, vascular, fairly well demarcated lesion. The dura mater was easily closed. A syrinx below the tumor explained the block at the 4th thoracic level.

Microscopic Examination. The tumor was very vascular. It was composed of spindle-shaped cells with indistinct cell borders and with dark-staining nuclei that showed little variation in size and shape. Occasional ovoid areas of hyalinized material were present and blood vessels with partially hyalinized walls were visualized. In spite of the absence of radial arrangement, the individual cellular elements were considered characteristic of ependymoma.

Course. Following surgery symptoms were greatly increased. Spasticity was marked and for 4 months he was able to walk only with crutches. One year after surgery there was still considerable spasticity, strength was normal except for some weakness in the right arm, and there was still some analgesia in the 4th and 5th fingers. He got around reasonably well with a cane, but could not be considered an excellent result. A myelogram 18 months after surgery showed an open canal and no apparent enlargement of the cord.

Case 4. Mrs. K.S.M., aged 36, was examined on Nov. 27, 1953. She complained of numbness in the hands and feet, present for 16 years, apparently caused by Raynaud's disease when she lived in the North. In 1951 she noticed weakness in the right index finger when typing so that she was unable to depress the keys properly. Shortly thereafter numbness developed in the right index finger and she burned herself without pain. Weakness in the right hand became so severe that she could not type at all and there was some involvement of the left hand. Subjectively there was involvement of the feet, although she was able to walk quite well.

Examination. Deep reflexes were definitely increased and Babinski sign was suggestive, with a transient ankle clonus. There was some difficulty in initiating urination. Pain and temperature sense were lost in C7 and C8 on the right and C8 and T1 on the left. A cervical myelogram showed typical findings of an intramedullary tumor without block, extending from C3 to C7.

Operation. On Dec. 22, 1953, a laminectomy of C3 to C7 was carried out and the dura mater was opened, revealing a greatly enlarged cord. No fluid could be aspirated, and the posterior spinal cord was then opened in the midline, revealing a red, soft tumor which was gently and gradually separated from the spinal cord and removed completely. Vessels passing from the spinal cord into the central canal were coagulated with the two-point coagulation forceps and cut as they were encountered. One large concretion was removed with the tumor. The total volume of the tumor was estimated at 3 to 4 gm. and it extended from C4 to the upper end of C7 vertebra.

Microscopic Examination. The tumor had the characteristic pattern of ependymoma with typical rosette formation.

Course. Following surgery there was no appreciable alteration in her neurological picture. There was no increase in reflexes, no Babinski sign, and there was good strength in both arms and legs. There was no disturbance of bladder. She was able to be up and about in 7 days and was walking quite well in 14 days. There was still some persistent weakness in the right hand, but this was not judged to be worse than before surgery and has already improved considerably.

Case 5. Mrs. L.H., aged 48, was examined Jan. 8, 1954. [This case is included through the kindness of Dr. George Ehni. My only connection with it was to help Dr. Ehni in the removal of her cervical intramedullary ependymoma.] Her chief complaint was pain in the arm.

Examination. The patient surprisingly had no neurological abnormality other than loss of the triceps reflex. She had received treatment by traction for a possible cervical disc, and myelographic demonstration of an intramedullary cervical tumor was something of a shock.

Operation. Laminectomy, C2 to T3, disclosed a large cervical ependymoma which was removed completely after dividing the posterior spinal cord in the midline (Fig. 1). Vessels extending from the tumor to the cord, chiefly in the region of the central canal, were coagulated with fine current and cut, allowing delivery of the tumor.

Microscopic Examination. The tumor was a typical ependymoma.

Course. Following surgery there was some general weakness, but very little neurological abnormality. There was no Babinski sign, but there was some difficulty in voiding so that a catheter was inserted. Four weeks after surgery she walked a

FIG. 1. *Case 5.* Total removal of intramedullary ependymoma, leaving a clean cavity in the spinal cord.

little hesitantly, felt tingling in her body from the middle of the thorax down and felt that her stomach was somewhat enlarged. She had not fallen in walking and there was no demonstrable weakness in the arms and legs. Deep reflexes were somewhat increased, but there was no Babinski sign, and the triceps reflex had returned. Vibratory sense was absent in the left lower extremity, but there were no other abnormal sensory findings.

Case 6. Mrs. F.G., aged 42, was examined Jan. 20, 1954. She had been operated upon 2 years previously in a clinic out of the State where partial removal of a cervical intramedullary ependymoma, extending from C5 to T2 vertebrae inclusive, had been carried out. She had not been able to walk before surgery, but improved after her operation so that she walked for about a year on crutches. Four months before admission her condition had gradually grown worse so that there was practically complete paralysis of the right leg and less than 50 per cent normal strength in the left.

Examination. A partial sensory level extended up to the 3rd thoracic vertebra, and there was hypalgesia up to the 8th cervical dermatome. Deep reflexes were markedly increased in the lower extremities, and a bilateral Babinski sign was present.

Operation. On Jan. 27, 1954, the old laminectomy incision was reopened and in addition to the lower three cervical laminae and 1st thoracic lamina which had been removed before, the 2nd thoracic was removed. A cystic cord was tapped and about 4 to 5 cc. of dark brown fluid were removed. The cord then was divided in the midline for the full extent of the tumor, which was then fully separated from the cord, as in the previous case. Solid tumor was estimated to weigh about 3 or 4 gm. and removal was felt to be complete.

Microscopic Examination. The tumor was composed of ependymal cells in pseudorosette formation. It was extremely well vascularized.

Course. There was no movement in the lower extremities for 10 days following surgery, but muscle tone was good, and there was no Babinski sign or ankle clonus. On the 10th day she began to move the left leg and to improve, so that 4 months later she was walking with help.

TABLE 1

Results of total removal of intramedullary ependymomas

Case No.	Sex	Age	Patient	Year of Operation	Location of Tumor	Neurology Before Surgery	Postoperative Survival	Postoperative Neurology
1	F	41	L.R.N.	1941	C7-T6	Unable to walk	Living 13 years	Negative
2	F	46	L. McA.	1942	C6-T4	Paresis legs	Expired from pneumonia and delirium tremens 5 days	
3	M	39	T. McG.	1952	C5-T1	Spasticity legs	Living 2 years	Good strength, marked spasticity
4	F	36	K.S.M.	1953	C3-C7	Marked weakness right hand	Living 6 months	Slight weakness right hand
5	F	48	L.H.	1954	C2-T3	Pain in neck	Living 4 months	Negative
6	F	42	F.G.	1954	C5-T2	Marked paresis legs	Living 3 months	Regained bladder control. Legs improved

SUMMARY AND CONCLUSIONS

Of 6 patients who were subjected to total removal of intramedullary spinal ependymomas, 3 have no significant disability (Table 1). It would appear that the chance of complete success is enhanced by early operation, encapsulation or good demarcation of the tumor, and use of the two-point coagulation forceps. While it should not be implied that all ependymomas are suitable for such a procedure, it is believed that in a good percentage of cases excellent results will be obtained by total removal.

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CASE REPORTS AND TECHNICAL NOTES

INTRAMEDULLARY CRYPTOCOCCIC GRANULOMA OF THE SPINAL CORD

B. RAMAMURTHI, F.R.C.S. (ENG.), AND V. C. ANGULI, M.D.
Neurosurgical Department, General Hospital, and Department of Pathology, Madras Medical College, Madras, India

(Received for publication July 12, 1954)

Cryptococcosis is an infection by the organism Cryptococcus neoformans, also known as Torula histolytica. The organism is a yeast-like fungus with special predilection to affect the nervous system. Though the disease is rare, it is now becoming more and more widely recognized. Carton and Mount[2] collected 220 reported cases of torulosis, in 42 of which neurosurgical procedures were performed. Usually the disease is a diffuse affection, though localized infection may occur. The circumscribed collection of the fungus is known as toruloma or cryptococcic granuloma. Balakrishna Rao and Lilauwala[1] and Liu[4] have reported circumscribed lesions of the brain that have been treated by surgery.

Involvement of the spinal cord by cryptococcosis is a very rare phenomenon. In 220 cases, Carton and Mount listed only 10 with spinal cord symptomatology. Of these 10, only 2 showed purely spinal cord symptoms (1 case of Goodhart and Davison[3] and 1 of Carton and Mount[2]). In Goodhart's case, though laminectomy was done twice, no tumour could be found. Carton and Mount had successfully removed a Torula tumour of the cauda equina and the patient was alive up to the time of reporting.

This paper, as far as we are aware, records the first case in the literature of a circumscribed intramedullary cryptococcic granuloma of the spinal cord that was successfully removed. The patient has been in good health for over a year, with no other manifestation of the disease. The cerebrospinal fluid on repeated examination showed no biochemical or bacteriological change.

CASE REPORT

N.S. 1307. Miss G., an Indian girl aged 17, was first admitted to the Government General Hospital, Madras in September 1952, complaining of pain in the upper part of her back since 1949. This pain radiated forwards around the left side of the chest and occasionally to the right at about the level of the nipple. For the last few months she had had difficulty in walking and felt her legs occasionally give way. On examination then, there were exaggerated jerks in the lower limbs. There was no other neurological abnormality. Roentgenograms of the spine were normal. Lumbar puncture showed clear, colourless CSF with an initial pressure of 80 mm. of CSF rising to 200 mm. on jugular compression. The biochemistry and cytology of the CSF were normal. She was sent home and asked to report for periodic examination.

On Dec. 10, 1952 the patient was readmitted with all the above complaints gradually worsening. Her legs had grown weaker with increasing pain in her back.

Examination. There was mild spasticity of the lower limbs with exaggerated jerks. The plantar reflex on both sides was extensor. There was no sensory loss. The bladder function was normal. Clinically the level of the lesion was clear because of the root pains, occurring at the 5th dorsal segment.

Roentgenograms of her dorsal spine were repeated and showed no abnormality. Lumbar puncture and manometry were repeated but there was no evidence of any block. The CSF was again normal, with 20 mg. protein and 4 lymphocytes per c. mm.

Lipiodol myelography through the cisternal route was done. Screening revealed a bifurcated obstruction of the iodized oil at the level of the 2nd dorsal vertebra. The swelling was seen to pulsate. The possibility of a vascular tumour or a haemangioma of the cord was considered.

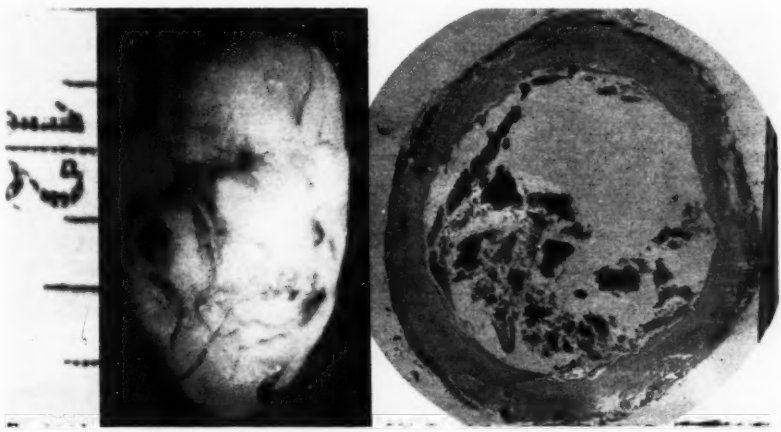
Operation. On Jan. 16, 1953, under endotracheal anesthesia, with the patient in the prone position, the laminae of D2, 3 and 4 vertebrae were removed. The extradural tissues were unusually vascular. The dura mater was opened. The spinal cord was found to be fusiform and bulging over a length of about $\frac{3}{4}$ inch, and it felt tense. There were a few small blood vessels coursing over this part of the cord, and these were coagulated by diathermy. Then the spinal cord was incised in the posterior midline, and the tumour was dissected out of the cord substance very carefully. The dura mater was closed and the wound was sutured in layers.

Course. The postoperative period was smooth. The patient recovered except for some weakness in the right lower limb.

A year later she was found to be normal and healthy. Lumbar puncture at this time yielded normal CSF. No organisms were grown in culture. Roentgenograms of her lungs were normal.

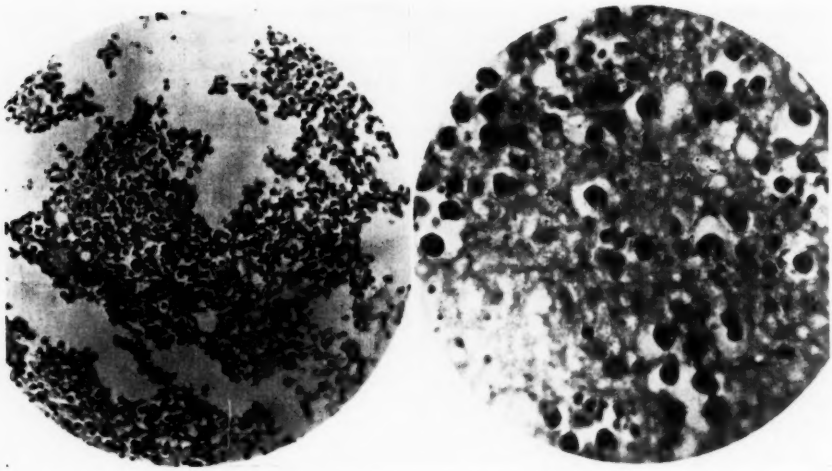
Pathological Study. The specimen was a firm greyish-pink oval tumour mass, measuring $\frac{5}{8}$ in. in length and $\frac{3}{8}$ in. in width (Fig. 1). It appeared encapsulated, there being no adherent nerve tissue over its surface. Fine capillary vessels were seen to course over the mass.

Section of the mass disclosed a cystic cavity containing gelatinous necrotic material. This was surrounded by a moderately thick wall, forming a capsule (Fig. 2).



FIGS. 1 and 2. (*Left*) The encapsulated tumor mass. (*Right*) Microphotograph, ×10. Section through the tumour showing a single cyst with a fibrous wall and containing granular material.

Microscopic Examination. Section through the mass showed a single cyst with an outer fibrous capsule and containing granular tissue within which were numerous spheroid bodies (Fig. 3). These had the appearance of Torula histolytica—small yeast-like bodies approximately the size of an erythrocyte. They were grouped in jelly-like masses, lying free as though in culture. In the vicinity of the collagenous fibrous wall organisms with a dark central portion and a surrounding greyish-white halo were seen, representing the gelatinous capsule (Fig. 4). Paucity of inflammatory cells was conspicuous. Only a few round cells were present here and there. The fibrous wall was without any appreciable inflammatory reaction.



FIGS. 3 and 4. Microphotographs. (*Left*) Numerous spheroid bodies lying free in the gelatinous granular mass (×160). (*Right*) Torula histolytica within the granular contents of the cyst. The halo around the spherules represents the capsule of the Torula bodies (×640).

Comment. There was no evidence of any systemic infection in this case. The Torula infection simulated a spinal cord tumour. Radical excision of the circumscribed mass seems to have resulted in a cure in this case. The patient was given no specific antibiotic therapy.

SUMMARY

A case is reported of an intramedullary cryptococcic granuloma of the spinal cord at the 5th thoracic segmental level. This is apparently the first such reported case in the literature, in which surgical removal of an intramedullary toruloma of the spinal cord has been done.

Our thanks are due to the Dean, and the Professor of Pathology, Madras Medical College, for permission to publish this case.

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RUPTURE OF AN INTRACRANIAL ANEURYSM DURING CEREBRAL ANGIOGRAPHY

KENNETH G. JAMIESON, M.S. (Melb.)
Repatriation General Hospital, Heidelberg, Victoria, Australia

(Received for publication July 14, 1954)

Cerebral angiography is now well established as a valuable means of investigating patients with a variety of intracranial lesions, and is being used more generally and more frequently. That it is not free from danger is apparent from the several deaths and many cases of hemiplegia that have been reported as complications (for example, see Rowbotham *et al.*[2]). The present case warrants separate report, as an intracranial aneurysm was seen radiographically to have been ruptured during the procedure.

CASE REPORT

A man aged 36 years was admitted on Feb. 3, 1954. Two days before, during strenuous exertion, he had experienced a sudden severe pain which began in the nape of the neck and spread over the head. He lost consciousness for about 1 hour and awoke with severe headache, a stiff neck and blurred vision, and vomited copiously. Examination then revealed no abnormality other than stiffness of the neck. Lumbar puncture yielded heavily blood-stained CSF.

Examination. On admission he still complained of headache, which was subsiding, and showed no abnormal neurological signs. The CSF was yellow and pressure was 180 mm. CSF. A diagnosis of ruptured intracranial aneurysm was made.

Course. After 1 week the patient was free of headache.

Angiography. Percutaneous injection of both common carotid arteries was performed under local anaesthesia on Feb. 10, 1954, and an aneurysm was demonstrated on the left middle cerebral artery, about half-way out the Sylvian fissure. The site of origin of the aneurysm was not well seen, nor whether it had an accessible neck.

The patient remained free of symptoms during the next week, but surgical treatment was deemed advisable. It was thought that the operation of choice would be carotid ligation in the neck, but to decide the possibility of a direct intracranial attack, further angiography was undertaken on Feb. 17, 1954, with the object of obtaining two further views.

The left common carotid artery was again punctured under local anaesthesia, and by the injection of 15 ml. of 40 per cent Uriodone a good anteroposterior view of the intact aneurysm was obtained through the orbit (Fig. 1). The other view required was an oblique lateral, to separate the aneurysm from bony shadows. Three injections were made to obtain this view—the first two films were fogged because the exposure was angled across the plane of the grid lines, but this error was then recognized and corrected and the next injection resulted in the picture seen in Fig. 2. Immediately after this injection, the needle was withdrawn from the artery (since success seemed assured) and the patient was removed to the waiting room. When the film was developed, the rupture was recognized and the patient was questioned regarding the effect of the injections. The first three injections had produced the usual feeling "like scalding water" up the left side of the face. The last injection had caused a similar sensation together with a sudden severe left frontal headache, which was still present. His speech was already a little hesitant. Examination showed no other abnormality at this stage, except for slight dilatation of the left pupil (a not uncommon effect of angiography).

FIG. 1. A-P projection of common carotid angiogram. The middle cerebral aneurysm is intact.

Course. The patient was returned to bed, and an early operation was planned. There was no apparent change in his clinical state until 1 hour later, when an epileptic fit commenced on the right side and resulted in unconsciousness. The left pupil was then smaller than the right, but it rapidly dilated and a left medial rectus palsy developed as unconsciousness deepened. An elevated B.P. (180 mm. Hg systolic) and slow deep respirations completed the picture of cerebral compression.

Operation (performed by Mr. R. S. Hooper under endotracheal gas and oxygen anaesthesia with controlled hypotension). A left frontotemporal osteoplastic flap was reflected and incision of the tense dura mater exposed the swollen Sylvian region. There was much subarachnoid blood in the cerebral sulci, and the high tension prevented retraction of the frontal lobe for the usual approach to the aneurysm via the Sylvian fissure. Brain needling encountered a large intracerebral haematoma at a depth of 3 cm., and this was evacuated by aspiration and by incision of the overlying cortex. The aneurysm was then found to be wrapped around the front of one of the middle cerebral branches, which had to be clipped to control the severe haemorrhage that resulted from dissection.

Course. After the operation the patient appeared definitely improved, but there were signs of decerebrate rigidity. Ten hours later his condition deteriorated, and cardiac and respiratory arrest occurred. Cardiac massage restored regular strong cardiac contractions, but spontaneous respiration did not recover and death soon followed.

DISCUSSION

The controversy that has raged over the advisability of early angiography in cases of spontaneous subarachnoid haemorrhage has largely been settled. The great importance of the information so to be gained, without which surgical treatment cannot be planned, considerably outweighs the risk of rupture of an aneurysm by the injections. Indeed, this risk has seemed rather remote. In the present instance there is a clear demonstration of such an occurrence. In Fig. 1 the aneurysm is intact and in Fig. 2 it has ruptured, while the onset of headache was during the last injection.

The fountain of dye seen spurting from the aneurysm well illustrates the force

with which such a haemorrhage may tear the brain substance, especially when adhesion of the aneurysmal sac to the brain has resulted from a previous subarachnoid haemorrhage. The rapid progression of neurological abnormalities, from headache and dysphasia to coma and cerebral compression is also evidence of the major character of the haemorrhage. It is unusual for haemorrhage to be actually shown by angiography, the only other case in my series being an extradural haematoma in which the bleeding point on the middle meningeal artery was visualized.[1]

At this Hospital, 40 per cent Uriodone has been used routinely for cerebral angiography, as this concentration appears to be necessary to obtain adequate contrast in the anteroposterior projection in particular. The amount of dye in the syringe for each injection is not more than 15 ml., except for cross-circulation tests, when up to 20 ml. are used. Not all of this is injected, the last 1–2 ml. being retained in the downward-pointed syringe as an additional precaution against the introduction of air bubbles (for these or clots caused by inadequate technique may account for a proportion of the reported complications). The pressure applied is that of the thumb on the plunger, which delivers the dye in 2–3 seconds through a 3-inch 18 G. needle.

The degree of vascular disturbance caused by radio-opaque solutions of the iodine group may be seen from the bright facial flush and scalding which follow injection. In this patient it was noticed that the flush was preceded by an intense unilateral pallor, which lasted about 5 seconds. That the cerebral vessels may behave similarly is suggested by the frequent finding of some degree of arterial spasm in the films—for example, in the carotid siphon in Fig. 2. Occasionally spasm may account for complete non-filling of one or more cerebral vessels which have been demonstrated in other injections. In one instance recently the internal carotid artery appeared to end blindly just below its bifurcation, while the ophthalmic and anterior

FIG. 2. Subsequent lateral projection shows rupture of the aneurysm with escaping jet of dye.

choroidal branches were filled to the periphery, showing that the exposure was correctly timed. A subsequent injection showed the cerebral vessels fully. (No neurological disturbance occurred in this patient.) Further, the sudden facial scalding causes a reflex elevation of blood pressure, which may also be serious.

When one considers the large number of complications that have occurred after use of these dyes, one wonders how much safer they are than thorotrast which, apart from its possible late carcinogenic effect, was non-irritant and gave excellent contrast radiographs in small amounts with slower injection. Certainly the need for a new non-irritant and good contrast dye is great.

This case has been the only serious untoward event in a series of 150 patients who have undergone carotid angiography (in many cases bilateral) at this Hospital in the past 3 years. Two transient complications have occurred. In 1 patient acute bronchospasm developed, which was relieved by the injection of adrenalin. Another became unconscious with profound hemiplegia 5 minutes after the conclusion of the angiogram, presumably from spasm as recovery was complete within 1 hour and no EEG abnormality could then be demonstrated. Comment may be made upon the unfortunate chance that the fourth injection in the present case should have been necessitated by a simple technical error in two previous films.

SUMMARY

1. A case of rupture of an intracranial aneurysm during cerebral angiography is reported, and the radiographic picture of haemorrhage from an aneurysm is presented.

2. The possibility of this complication is a real one, but should not preclude the early use of this valuable diagnostic procedure.

3. The need for a new non-irritant radio-opaque dye is discussed.

I am indebted to the Chairman of the Repatriation Commission of Australia for permission to publish this case. It is a pleasure to thank Mr. R. S. Hooper, Neurosurgeon to this Hospital, for his continued advice and guidance, and for his ready surgical assistance in this case.

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SPINAL CORD TUMOR IN A NEWBORN*

DWIGHT PARKINSON, M.D.,† HARRY MEDOVY, M.D.,‡ AND J. R. MITCHELL, M.D.§
University of Manitoba, Winnipeg, Canada

(Received for publication July 23, 1954)

CASE REPORT

W.G.H. #71685. D.B., a white male child, was born Dec. 15, 1953 at the Maternity Pavilion of the Winnipeg General Hospital following a normal pregnancy in a healthy primipara, aged 32. Labor was normal; the first stage lasted 24 hours and the second stage 15 minutes. Outlet forceps were used. The infant cried immediately and was of normal color. It weighed 7 lbs. 5 oz. The obstetrician noted that the baby did not move his left leg either spontaneously or on stimulation and that his right leg moved only very slightly with stimulation. There was no evidence of injury.

Examination. The baby was re-examined the next morning. The cry was normal and the feeding was normal. The upper half of the body appeared entirely normal. The configuration and color of the lower half of the body appeared normal. Tonus, however, was markedly reduced in the lower extremities. The anal sphincter was extremely patulous and digital examination occasioned no discomfort. Urine dribbled with each cry. There was no movement in the left leg and the right leg moved but slightly at the hip and knee. There were no tendon reflexes in the lower extremities. The left cremasteric reflex was absent whereas the right was quite brisk. Pain response was reduced on the left from the perineum up to the lower abdominal quadrant and on the right up to approximately the inguinal region. There was no visible or palpable defect of the spine, no tuft of hair and no sinus. X-ray of the entire skeleton revealed no abnormality. A lumbar puncture at the 4th interspace recovered three drops of xanthochromic fluid. Unfortunately this was not deemed sufficient for examination by the laboratory.

Course. Weekly checks revealed no significant progression. After 7 weeks it was felt definitely established that no improvement was taking place. There remained a neurologic deficit with the upper level at approximately T11 on the left and L1 on the right.

The child was re-admitted for myelography at the Winnipeg General Hospital. Attempts at lumbar puncture were unsuccessful and hence the opaque media was introduced via the cistern. A complete block to the downward passage of the opaque media was demonstrated at T8 (Fig. 1).

1st Operation. At laminectomy, Feb. 9, 1954, a dark blue fleshy mass was exposed at T12. At this level it lay primarily on the left of the cord (Fig. 2) and appeared to be entirely extramedullary, thinning out in the subarachnoid space and completely enveloping the cord up to T8. This mass was removed downward to L2. At this time the child's condition worsened and the operation was discontinued.

Course. The microscopic appearance of the tumor was that of an undifferentiated glioma and therapy was instituted with the cobalt bomb. The child failed to improve and re-operation was therefore undertaken.

2nd Operation. On April 13, 1954 the laminectomy was continued, and the mass was followed down to the lumbosacral junction, at which point the tumor terminated.

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† Department of Surgery, Winnipeg General Hospital, University of Manitoba.
‡ Department of Pediatrics, University of Manitoba.
§ Department of Obstetrics and Gynecology, Winnipeg General Hospital Maternity Pavilion.

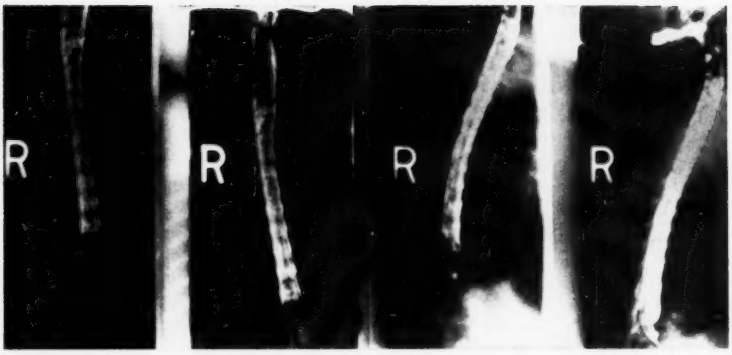

FIG. 1. Cisternal myelograms taken with patient vertically upright. The leading edge in both the A.P. and lateral views of the downward passage is arrested at T8. In the A.P. views the leading edge is seen to be widened and concave.

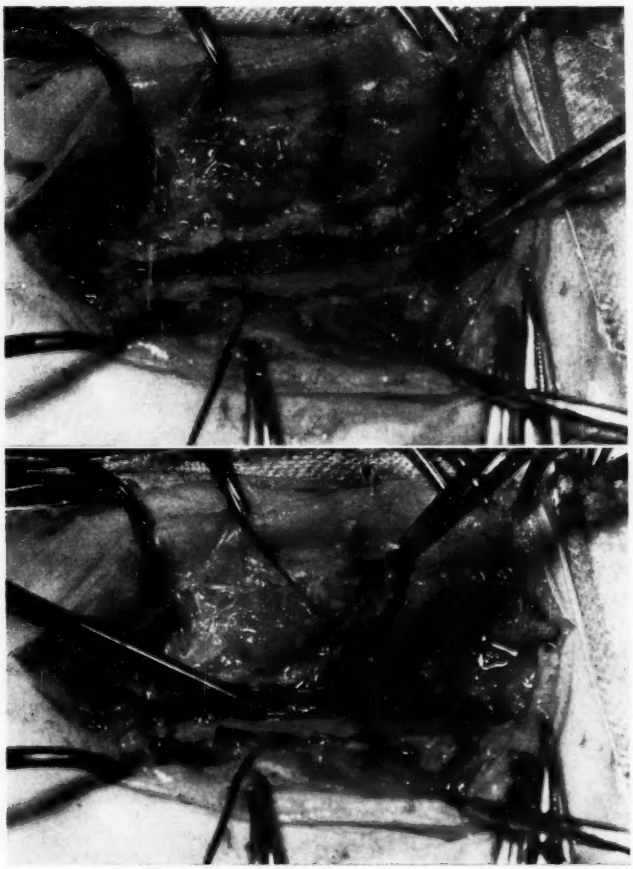

FIG. 2. (*See explanation on facing page.*)

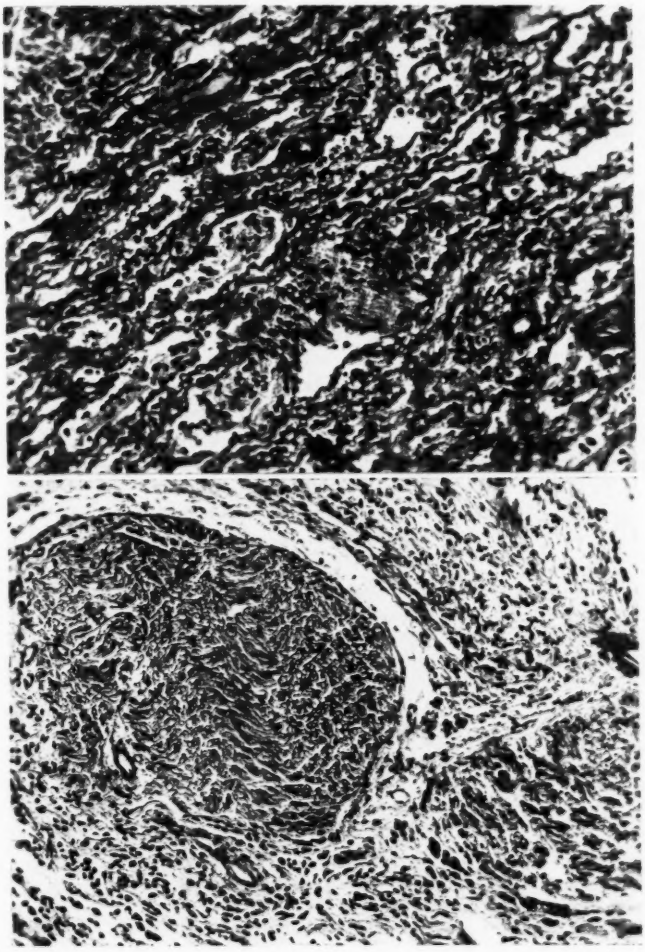

FIG. 3. (*Above*) Irregular clusters of darkly staining anaplastic nuclei in cells with very scanty cytoplasm. The supporting structure is a very loose reticulum containing numerous irregular blood vessels with walls of uneven thickness. Hematoxylin and eosin, ×125. (*Below*) Another section containing a nerve rootlet, the sheath of which is invaded by tumor cells in the uppermost portion. The nerve root itself is invaded with tumor cells in the lower portion. Hematoxylin and eosin, ×125.

FIG. 2. (*Above*) Operative exposure. The main bulk of the tumor is seen above the cord as a raw surface. The part encircling the cord on top has been peeled off and the ragged margin on the other side appears in the picture just below the cord, to the right of where the dural suture is holding up the free edge of the dura mater. (*Below*) The main mass of the extramedullary tumor being removed from its position lateral to the cord (above cord in this picture).

Microscopical Diagnosis. The consensus of the pathology department at this time was that the tumor is a malignant glioma, possibly a neuroepithelioma (Fig. 3).

Subsequent Course. The child continues to thrive in every respect. Movement in the right leg has become quite vigorous and movement has appeared at both the hip and knee of the left leg. The sphincters have returned to apparent normalcy. Complete recovery is not anticipated.

DISCUSSION

Spinal cord tumors are quite rare in childhood and particularly in infancy.[1–16] Broager's[4] youngest patient in a series of 271 cases of cord tumor was 9 years old. Anderson[2] reported a total of 21 cord tumors in children, excluding congenital malformations. His youngest patient was 5 months old, and had an extradural hemangioendothelioma. Of 36 patients with cord tumor reported by Dandy,[7] 5 were under 15 years of age. Ford[9] found 3 cases among 70,000 pediatric admissions and the youngest patient was 9 years old. Of Stookey's[16] 160 patients with cord tumor, 8 were under the age of 12. Elsberg's[8] youngest patient was 3 years old. Buchanan's[6] youngest patient was 3 months old. We have been unable to find any recorded case of a spinal cord tumor evident at birth other than teratomas, dermoids and those associated with developmental defects such as bifida, meningocele or sinus.[15]

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A NEW TYPE OF TANTALUM CLIP FOR OCCLUDING CEREBRAL BLOOD VESSELS

BURTON L. WISE, M.D., AND ELIOT D. GREEN*
Department of Neurological Surgery, University of California School of Medicine, San Francisco, California

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In the course of intracranial operations on aneurysms and arteriovenous angiomas, it has become apparent that the usual narrow tantalum or silver clips are often inadequate for occluding large vascular channels, such as the internal carotid artery or the principal contributing vessels of an angioma. There is also the risk, particularly in the case of an angioma, that these narrow clips may cut through or cause erosion of the vessel.

To overcome these disadvantages, at the suggestion of Dr. E. B. Boldrey a number of plain broad tantalum clips were made up. When they were put to use, however, we found that although they were superior to the narrow type, they had a tendency to slip in spite of serrations on the inner surface. Recently, during the course of an operation, one of these clips was seen gradually to slide off a large artery feeding a parietal angioma.

We then constructed another clip, using the same wider dimension but incorporating a flange to prevent slipping (Fig. 1). This clip has been used at the University of California Hospital and has proved quite satisfactory for the occlusion of larger intracranial vessels. It is made from 16/1000″ thickness (0.4 mm.) tantalum sheet and can be cut or stamped with a small die. The main body of the clip, before it is bent, measures 14 mm. by 3 mm., and the narrow flange on one end is 2 mm. long by 1 mm. wide (Fig. 1). The internal surfaces are serrated to alleviate longitudinal slipping of the clip on the vessel. The broad part of the clip is shaped to form a "V" or "U" and the narrow flange is bent up perpendicular to the surface of the clip, partially closing the "U" or "V" (Fig. 1). We have found that a straight hemostat, either standard or long-handled type, is adequate for applying the clip. When the clip is closed, the narrow flange prevents it from slipping off the vessel.

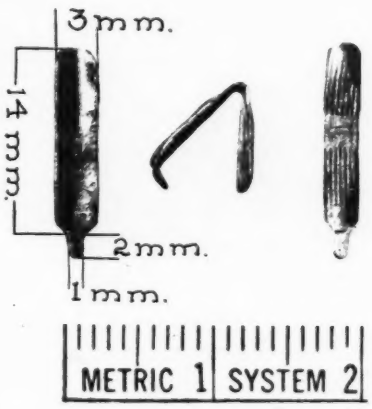

FIG. 1. Clip shown about 2½ times actual size. (*Left*) External surface of clip, before bending, showing slight longitudinal groove. (*Center*) Finished clip, ready for application. (*Right*) Internal surface of clip, before bending, showing longitudinal serrations.

* Instrument maker, University of California Hospital.

To obviate the risk that the clip might open gradually, we had planned originally to develop a special applying forceps which would bend the flange over as the clip was closed. After using the clips, however, we have come to the conclusion that this is unnecessary if the clips are stiff enough. If desired, the flange may be bent down after closing the clip.

SUMMARY

A new type of broad tantalum clip with a flange to prevent slipping is described

NOTICES

NEW YORK SOCIETY OF NEUROSURGERY

Dr. Percival Bailey, Professor of Neurology and Neurological Surgery, University of Illinois, Chicago, will deliver the 1954 Charles A. Elsberg Lecture established by the New York Society of Neurosurgery, on Tuesday, November 16, 1954, at 8:30 P.M., at the New York Academy of Medicine, New York City. Dr. Bailey has chosen as his subject "Psychomotor Epilepsy—Its Relation to the Visceral Brain."

Preceding the lecture, a dinner in Dr. Bailey's honor will be held in the President's Gallery of the New York Academy of Medicine.

SOUTHERN NEUROSURGICAL SOCIETY

The next annual meeting of the Southern Neurosurgical Society will be held in Birmingham, Alabama, February 18 and 19, 1955. Headquarters will be at Hotel Dinkler-Tutwiler. William F. Meacham, Vanderbilt University Hospital, Nashville, Tennessee, is Secretary.

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